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Cover illustration: Thin sections of several different habits of barite. Photographs: Jane Clarke.

Botryoidal barite Mag 538; ppl.	Acicular barite Mag 549; xpl.	Poikilotopic barite Mag 530; xpl.
Bladed barite (white) Mag 580; ppl.	Botryoidal barite Mag 538; xpl	Spherulitic barite Mag 584; xpl.
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The Geoff Brown Memorial Lecture: Radioactivity from Lakes to Lavas: Studies from Uranium series isotopes

Dr Louise Thomas, Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA

Introduction

Firstly thank you Joe (Jennings) for the introduction and secondly thank you to the OUGS for inviting me here today to give the Geoff Brown Memorial lecture. I am honoured to do so.

For those of you, who I've met (and I see lots of familiar faces in the audience) during my twelve years at the Open University, whether on the fieldtrip to Tenerife or at one of the number of lectures I have given at regional branches, or at Walton Hall you will be surprised to hear that this talk is not all volcanic, in fact that I have moved more than a little way towards the dark side – soft rocks. This talk encompasses work that I have been involved in at the OU, where we are currently the NERC facility for Uranium Series.

I will start with the history of radioactivity, what types and uses, what we have at the OU, then onto U-series, and how that works and finish off with some applications, including hard rocks! This talk covers a wide range of projects, many of which Peter van Calsteren, Mabs Gilmour and I have been involved with.

History of Radioactivity

During the mid to late 1800s, many physicists including William Thompson, later known as Lord Kelvin, had been working on the problem of the age of the Earth and the sun, using theories and estimates of cooling rates. Lord Kelvin concluded that the age of the earth was probably around 20 - 40Ma. This was too long for some and too short for others including Lyell's theory of gradual geological change and Darwin's theory of evolution. T.C. Chamberlin, a confessed agnostic in the audience added that there might be an as yet unknown source of energy.

Figure 1. Rontgen's X-ray image of his wife's hand with wedding ring (source http://nobelprize.org)

Henri Becquerel, the French physicist is attributed with the discovery of radioactivity in 1895, whilst he was experimenting with uranium salts. Almost at the same time as the German physicist Wilhelm Rontgen discovered x-rays (one of his first pictures was of his wife's hand, Figure 1), and soon after Marie Sklodowska-Curie discovered and isolated radium.

In the early 1900s the research into radioactivity continued, Ernest Rutherford amongst others had been studying radioactive processes, and he suggested that it might be possible to date rocks using radioactive minerals and within the next few years, uranium, thorium and radium isotopes were used to date minerals.

The age of the Earth was calculated to be in the billions of years, not millions. During a lecture to the Royal Institution on the heat production of radioactivity and its effect on the heat of the Earth, Rutherford was ill at ease to see Lord Kelvin in the audience. He avoided a potential explosive conflict, by announcing that Lord Kelvin had calculated the age of the Earth from its thermal history, provided no new source of heat was found. Therefore, Lord Kelvin has in fact anticipated the discovery of radioactivity and the heat produced by this phenomenon. Lord Kelvin who had in fact slept soundly through the rest of the talk, just beamed with pleasure (Source: Faure 1986).

The occurrence of radium excesses was first found in volcanics from Vesuvius by Joly in 1909. The importance of U-Series disequilibrium to the study of magmatic processes was only realised around fifty years ago from work by Oversby and Gast and Allègre, and since that time the subject has been in continuous development on a whole range of rocks.

Types of Radioactivity

I have mentioned both radiation and radioactivity. What is the difference? Radiation is the excess energy that is released as particles or rays, during radioactive decay, whilst radioactivity is the property of an atom that describes spontaneous changes in its nucleus that create a different element.

There are 3 main types of radiation:

- Alpha (He nucleus) (stopping distance 1-3cm in air or stopped by paper)
- Beta (electrons) (depends on energy but can travel several metres or stopped by perspex)
- Gamma (X rays) (up to kms - most energetic, goes through everything!)

Most alpha emitters occur naturally in the environment, for example, alpha particles are given off by uranium-238, and other members of the uranium decay series are present in varying amounts in nearly all rocks, soils and water. They are stopped by the dead layer of skin cells, however if they are ingested/inhaled then they can cause a lot of damage. Your home smoke detectors will have an alpha source – Americium 241. Alpha emitters were used as a cure for aches and pains and as luminous paint on watches and compass dials.

Beta particles are subatomic particles ejected from the nucleus of some radioactive atoms. While beta particles are emitted by atoms that are radioactive, beta particles themselves are not radioactive. It is their energy, in the form of speed, which causes harm to living cells. They are used in a wide range of medical treatments.

Gamma radiation is very high-energy ionizing radiation. Gamma rays and x-rays, like visible, infrared, and ultraviolet light, are part of the electromagnetic spectrum. While gamma rays and x-rays pose the same hazard, they differ in their origin. Gamma rays originate in the nucleus. X-rays originate in the electron fields surrounding the nucleus. Gamma emitting radionuclides are the most widely used in medicine and industry.

Annual Background Doses

Your annual background dose of radiation depends where you live in the country but the average for the UK is 2.6mSv per annum. 50% of that is made up of Radon. For those jet-setters amongst you, you should be aware that every flight from Heathrow to LA, you get a dose of 0.065mSv.

Walton Hall

Geoff Brown was a field geologist and much preferred to be out in the field, rather than in a lab. However he used to work with gamma radiation on the portable X-ray spectrometer, measuring major element concentrations in granites. In the Earth Sciences department today, radiation is used in three different methods. Argon dating, X-Ray Fluorescence to look at compositions (both portable and fixed) and U-series (that's us). The U-series facility consists of two ultra-clean chemical preparation laboratories, and a dedicated thermal ionisation mass spectrometer, we also share the Nu Plasma Ionisation Mass Spectrometer

Uranium-Series

Ok, so why bother? Well U-Series can provide us with dates, and there are two main reasons for dating environmental, geological and archaeological materials:

1) A precise age for a bone or a deposit underpins our understanding of its significance by establishing its archaeological or geological context.

2) The time-span between two dates of samples that were deposited under different conditions makes it possible to calculate the rate of change and may indicate the process that caused the change.

Uranium-series analyses are an essential component of many research projects in Earth and environmental science, oceanography, hydrology and science-based archaeology today. Topics range from magma chamber evolution and volcanic hazard prediction, global climatic change through dating of carbonate deposits, human evolution through dating of bone, to the study of groundwater evolution.

A U-series 'date' is not actually a geological age but the time since an element fractionation process, and if this process is fast relative to the time that has elapsed since fractionation, then it can be 'dated'. ^{238}U, ^{235}U and ^{232}Th decay through a whole chain of daughter isotopes to stable ^{206}Pb, ^{207}Pb and ^{208}Pb. However I'll be talking about a limited part of that chain today from ^{238}U to ^{226}Ra

The time since the fractionation process can be calculated with the decay equation:

$$-d\mathbf{N}/dt = \lambda\mathbf{N} \quad \text{or} \quad \mathbf{D} = \mathbf{P}(1-e^{-\lambda t})$$

Written out for ^{230}Th and normalised to ^{232}Th and taking into consideration that ^{230}Th is also radioactive and decays (to ^{226}Ra) the equation becomes:

$$\left(\frac{^{230}Th}{^{232}Th}\right)_{P \text{ or } M} = \left(\frac{^{230}Th}{^{232}Th}\right)_i \times e^{-t\lambda_{230}} + \left(\frac{^{238}U}{^{232}Th}\right)_i \times \left(1-e^{-t\lambda_{230}}\right)$$

Also known as the 'isochron equation' and it requires a number of datapoints to calculate an age.

Graphically, this is represented as an 'Equiline Diagram' (Figure 2).

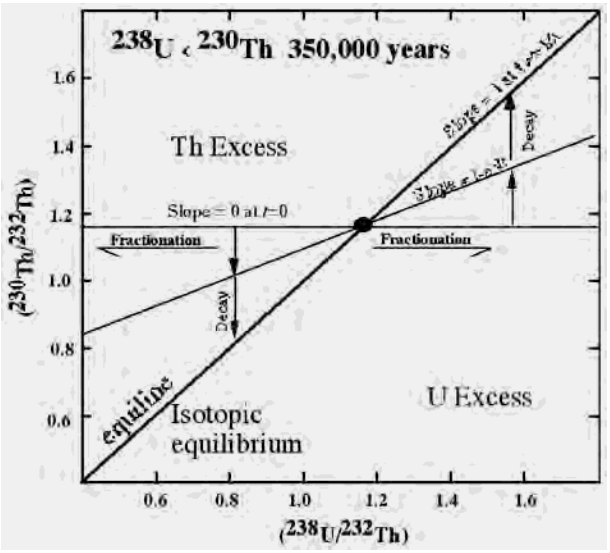

Figure 2. An Equiline diagram.

There are a couple of important facts about U-series systems, they have a known initial isotope ratio in secular equilibrium (ie on the equline) and the fractionation of U from Th daughter can be very efficient.

In environmental situations (ie soft rock/water) U is highly transportable in oxidised (hexa-valent) complexes where Th is insoluble.

Whilst in silicate systems U and Th are very similar and only fractionate at very small degrees of melting at high pressure. The range of U/Th in all silicates is <30%. Hence where we see a fractionation between U and Th, this must have taken place at small degrees of melting at high pressure.

Environmental Samples

In environmental samples U-series dating is almost exclusively carried out in authigenic phases, i.e. minerals that were formed in, or are precipitates of, the system of interest, such as calcite (inorganic precipitates in stalagmites or lake marl), and organic-mediated calcite; aragonite in coral and shells, or apatite (calcium phosphate) which forms almost exclusively in bone.

Uranium is a ubiquitous element in the natural environment, with concentrations ranging from ~3ppm in continental crust, 3.3ppb in seawater, river-water usually <0.3 ppb , whilst groundwater and hydrothermal waters can contain more than a ppm.

Marls

Shallow fresh-water lakes in limestone areas usually have bottom sediments often referred to as marls that consist of fine-grained limestone detritus and authigenic carbonate precipitate. Fresh-

water precipitates contain uranium from the riverine input and tend to be relatively low in uranium, unless the rivers also drain a high uranium basement geology such as black shale or granite. Pore-water in marls becomes reducing from the decay of organic matter usually close to the water-sediment interface and this stabilises the uranium.

Marls can be a very useful environment archive (fossils, pollen, $\delta^{18}O$ and $\delta^{13}C$) because bioturbation tends to be limited in the reducing environment below the water-sediment interface.

However exposure, especially to water percolation, ruins the U-series 'closed system' in marls. Another problem is that many authigenic materials contain significant amounts of 'inherited' ^{230}Th from silicate, (clay from the drainage area, wind-blown dust or volcanic ash), and marls often are the worst (Figure 3).

Figure 3. Marl, Lake Puiray, Prof J Lowe.

It is necessary to correct the sample for the detritus. The detrital effect is greater on the younger samples so that an age of 3000 years can be miscalculated by 1500 years when 5% silicate is added into the system.

Speleothems

Limestone deposits erode mainly by dissolution in carbonic acid forming from water that is charged with dissolved CO_2 derived from organic matter decay and soil respiration in vadose zones. The result of this largely inorganic precipitation of calcite is called 'speleothem' (from the Greek for cave deposit) and encompasses stalagmites, stalactites, flow-stone tufa, and encrustations of objects, including fossils. Stalagmites, stalactites and flow-stone form in caves, tufa forms at or near springs and encrustations in both.

Stalagmites are usually considered the sample of choice because successive layers of calcite are neatly deposited on top of each other in the centre of a drip mound, from a well-defined drip point at the tip of a stalactite. Layers are also draped over the sides of the mound, usually still in an orderly fashion but mostly too thin for successful sampling for U-series dating. Stalagmites tend to be low in 'inherited' ^{230}Th from external phases, and many characteristics such as morphometry, fluorescence index, trace element

Figure 4. Stalagmite from caves under Chepstow.

ratios and stable isotope ratios (hydrogen, carbon, oxygen, among others), and pollen have been studied in multi-proxy approaches (Figure 4).

Upwards of 30 papers per year have been published on speleothems in recent years ranging from the timing of sapropel formation in the Eastern Mediterranean; millennial-scale climatic variability over the past 25,000 years in Southern Africa; 215ka history of sea-level oscillations from marine and continental layers in Italy, and climate oscillations during the last deglaciation from Tangshan Cave China.

An example of a paper that combines the use of environmental indicators was published by Genty *et al.* (2003). The authors correlate the terrestrial with the marine and ice-core age record to evaluate variations in $\delta^{18}O$ in a stalagmite, Vil9, the GISP ice core and MD95 sediment core, with the conclusions that temperature in the Dordogne during the Villars cold phase was probably more than 10ºC below current averages and permafrost would have been widespread in the area.

Stalagmites frequently show evidence of complicated growth history revealed by deposition hiatuses caused by changes in hydrological conditions as a consequence of climate variations such as dry periods or episodes of glaciation. Other interruptions in the steady-state deposition regime are caused by cave flooding which results in detritus-rich layers. Deposition can also be interrupted by seismic activity that may even topple stalagmites.

An example of flowstone dating comes from Creswell Crags, a limestone gorge with caves and smaller fissures on the Nottinghamshire-Derbyshire border.

In 2003 we worked with Alistair Pike (Bristol) and dated a piece of flowstone at 12,800 years old. This has formed over some rock art, and proved to be the discovery of Britain's only known Ice Age rock art. Many bones of animals such as wolf, bear, lion, horse, giant deer, reindeer, bison, arctic hare and arctic lemming which lived during the Ice Age were also found in the caves.

Organic-mediated carbonate

That is to say organisms which have an organ support structure

consisting of calcite or aragonite that has been precipitated with the aid of enzymes. Simple organisms such as corals and forams are easier to date as they tend to have higher U contents, providing they have not been exposed to rainwater.

Complex organisms such as gastropods and molluscs have always been considered as difficult to date by U-series methods; approximately half of the analysed samples yielded ages that did not fit in with established chronologies. However, molluscs such as Cardium and Anadonta, have been successfully dated recently with U-series methodology. The previously encountered difficulties can be partly explained by the relatively low initial U/Ca and uranium concentration in gastropod and mollusc shells which leads to uranium absorption from seawater after death.

Igneous systems

U-series in igneous systems can give a wide range of information, it is not only a dating tool.

We can use U-series systematics to constrain rates and time scales of melt generation, differentiation, residence time scales, extraction from source regions, fluid flux at subduction zones, and mantle wedge dynamics. We can gain insights into the source composition of volcanic suites. One important factor is that the mantle retains U relative to Th during partial melting and hence can generate the excess Th seen in Ocean Island Basalts and Mid Ocean Ridge Basalts. The only way to fractionate U from Th is at high degrees of pressure and small degrees of melting and in the presence of garnet, high pressure amphibole or in some case phlogopite giving us an indication of the depth and conditions of source.

I worked on ocean island volcanics on Iceland and in the Canaries (the latter for my PhD thesis). On Tenerife, we looked at a time scale of differentiation or evolution from the most mafic to the most evolved magma taking in the order of 200,000 years in at least two magma chambers. In Lanzarote, the source of 1730-36 eruption was at a depth of 60 to 70km below the surface and was maintained at a similar composition for a relatively long time.

Finally one of our recent proposals is to look at the magmatic fractionation rate at the active lava lake in Erta'Ale (Figure 5).

Conclusions

U-series dating can be used where other systems e.g. ^{14}C cannot reach.

U-series can be a powerful dating tool.

However, U-series is not foolproof, and it is not simple, but that keeps it interesting!

Figure 5. Erta'Ale Gezahegn Yirgu.

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For Further discussion on U-series see:

Calsteren P van, Thomas L E, 2006, Uranium-series dating applications in natural environmental science. *Earth Science Reviews*, **75**, 155-175.

Bourdon, Henderson, Lundstrom and Turner (eds), 2003, Uranium Series Geochemistry Review *In: Mineralogy and Geochemistry Volume 52 Geochemistry Society Mineralogical Society of America.*

Ours is U-series in environment whilst Bourdon *et al.* is everything you ever wanted to know about U-series!

Information about Kelvin, Becquerel and Rutherford is from Faure.

Evolution of Fossil Ecosystems by P Selden and J Nudds, 2004, Manson Publishing Ltd., 160pp, £19.95 (paperback) ISBN 1840760419.

Despite its rather misleading title, this well-illustrated book describes various Fossil Lagerstätten throughout the World. Fossil Lagerstätten are deposits which contain far more complete assemblages than are usually found. They occur when some event has buried an entire commmunity in a very short period of time, before all soft parts can be degraded; thus details which are usually not evident can now be seen.

The authors describe an overview of each site: its history (who found it, worked on it etc.); its place in the stratigraphic record and a detailed description of the fossils themselves.

As well as describing the well-known sites: The Burgess Shale; Ediacara; The Rhynie Chert; Mazon Creek, Sonhofen and Grube Messel, other, less famous, sites are also included: The Soom Shale; The Hunsrück Slate; Grès à Voltzia; The Holzmaden Shale; The Morrison Formation; The Santana and Crato Formations; Baltic Amber and Rancho La Brea.

The authors have not confined themselves to the original sites where the Lagerstätten was found. In recent years comparable Lagerstätten sites have been unearthed globally; for instance the Chaomidrazi Formation in Liaoning Province in China has produced Solnhofen-like specimens with superb preservation of soft parts. There is a map that shows where these similar Lagerstätten are located.

This book is easy to read and can be understood by the amateur as well as the informed geologist. At £19.95 it will soon be on my bookshelf.

Jane Clarke MPhil (Open)

Giant landslides, lava flow fields and the edge of the known world (1491): an introduction to the geology of El Hierro, Canary Islands.

Duncan Woodcock

Introduction

On his second trip to America in October 1493, Christopher Colombus wrote in the ship's log: "Punta de Orchilla, the last visible sign of the European world" as he passed the western end of El Hierro (VISTA Lanzarote 2004). Before his first trip to America a year earlier this location was considered to be the edge of the known world. In the second century AD, the Greek mathematician and geographer Ptolemy defined the Prime Meridian to run through Punta de Orchilla. Later a lighthouse, the Faro de Orchilla, was built to mark the spot. In October 1884, the Prime Meridian was relocated to run through the Royal Observatory at Greenwich and El Hierro slipped into obscurity (Wikimedia Foundation, 2006).

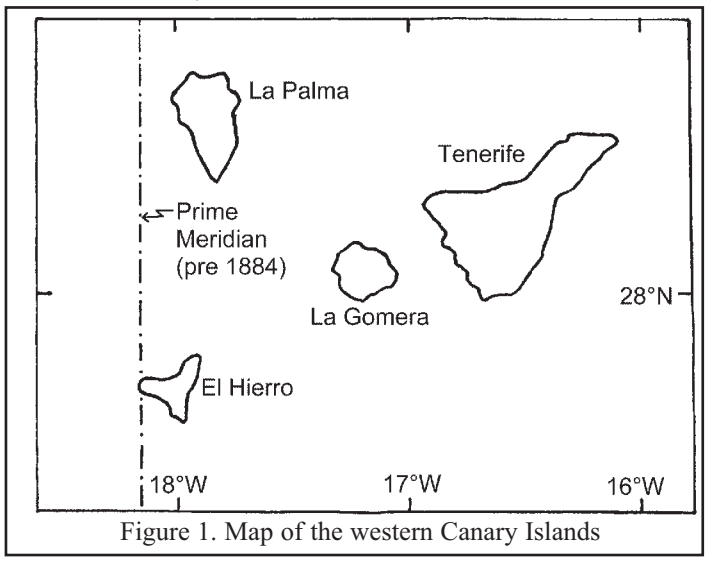

Figure 1. Map of the western Canary Islands

El Hierro is the smallest, least populated and most remote of the Canary Islands (Figure 1). It rises steeply from the sea and the centre of the island is often enveloped in mist and fog. The disused Faro de Orchilla still stands on a desolate western shore surrounded by lava flows. On a foggy day it still has the feel of the "edge of the known world" about it.

This paper arose from a week's visit to El Hierro in March 2006, when I was able to visit most of the locations in the recently published field guide (Carracedo & Day 2002). I spent additional time looking at the lava flow fields in the south of the island: this location has the distinct advantage of being free of the cloud and mist that can be a feature of much of the centre of the island.

Geological Overview

El Hierro is the youngest of the Canary Islands with the oldest subaerial lavas dated at around 1.2Ma. The shape of the island (Figure 2), comprising three lobes separated by large embayments, is the product of several stages of subaerial growth and collapse of a basaltic shield volcano (Carracedo *et al.* 2001,2002). Figure 3 summarises the geological history of El Hierro.

The first subaerial stage comprised the growth of the Tiñor volcano from the eruption of lavas and pyroclasts from a central vent between 1.2 and 0.8Ma. This stage was terminated by a major collapse of the NW flank of the volcano.

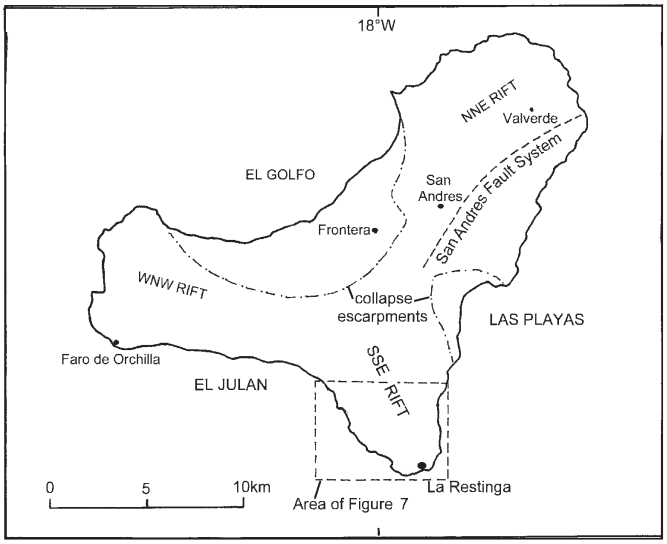

Figure 2. Map of El Hierro.

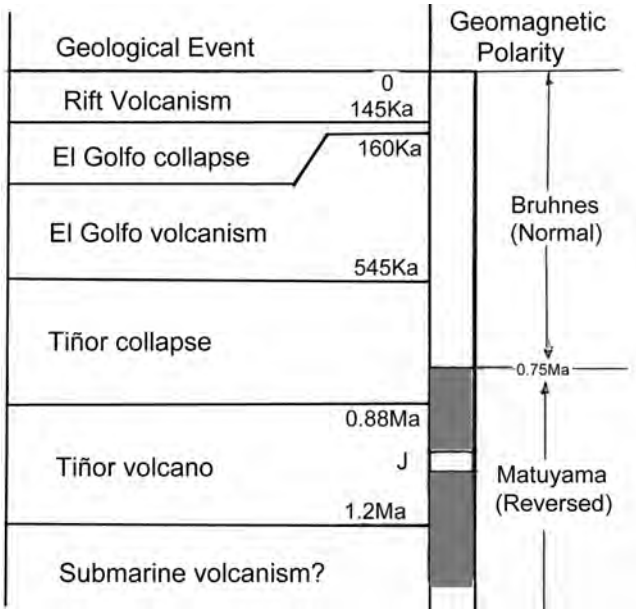

Figure 3. Summary of the main events of the subaerial geology of El Hierro. The interval labelled J on the geomagnetic polarity chart corresponds to the Jaramillo normal polarity interval (0.996 – 1.053Ma) within the larger Matuyama reversed polarity interval.

The second stage of volcanism started around 0.6Ma when lavas and pyroclasts erupted from a central vent and filled the Tiñor collapse scar to develop a large shield volcano known as the El Golfo volcano. Construction of this unstable edifice was followed by collapse to the south (the El Julan collapse) and, more recently, to the WNW (the El Golfo collapse).

Since the collapse of the El Golfo edifice, volcanic activity has been distributed along a three-armed rift system, with all branches simultaneously active. At present El Hierro is volcanically quiescent, with the most recent activity dated at around 500 BC. This

Figure 4. The north wall of the El Golfo escarpment from the viewpoint at km 20 on the TF912 road to Frontera.

quiescence contrasts markedly with El Hierro's northerly neighbour La Palma, where there have been seven eruptions in the last 500 years.

Giant lateral collapses

The El Golfo embayment is the most spectacular landform on El Hierro. It is around 15km across from NE to SW and extends up to 5km inland from the coast to headwalls around 1000m high (Figure 4). The embayment was originally thought to be the remains of a large central caldera; others have considered creation by fluvial erosion or landsliding (Gee *et al.* 2001). Submarine investigations using sidescan sonar off El Hierro in the 1980s revealed a huge debris avalanche deposit offshore of El Golfo. The discovery of this huge area of blocky volcanic debris, which contains angular blocks up to 1.2km across and 1-200m high, gave strong support to the theory that El Golfo was formed by a giant lateral collapse (Masson 1996).

Correlation of the debris avalanche deposit with turbidite layers in the Madeira abyssal plain suggests that the collapse is as young as 13-17ka (Carracedo *et al.* 1999). Onshore evidence, mainly derived from the numerous water boreholes that penetrate the coastal plain in front of the embayment, suggests a much older date. These boreholes have revealed a marine abrasion platform partly covered with breccias and aeolian sands; partly covered in turn by subaerially erupted post-collapse lavas dated at around 130ka.

Figure 5. The El Julan collapse scar, now completely infilled with Rift Series lavas, such as those in the left centre of the photograph. View from Tacaron area.

The El Golfo embayment was produced by the most recent lateral collapse on El Hierro. The sidescan sonar survey identified a number of older offshore debris avalanche deposits around El Hierro. A large debris avalanche deposit offshore to the SW of the island projects back to the El Julan embayment. This 16km long embayment has relatively shallow seaward-dipping slopes (Figure 5): the original collapse scar has been almost completely infilled by post-collapse lavas from activity along the WNW rift zone. This infill sequence has not yet been fully investigated; the oldest lavas so far recovered from water exploration boreholes are dated at around 150ka (Carracedo *et al.* 2001).

The oldest giant lateral collapse on El Hierro was associated with the collapse of the first subaeriel volcanic edifice, the Tiñor volcano, at around 0.8Ma. The Tiñor collapse scar was completely filled by volcanic products of the more recent El Golfo volcano. Onshore evidence for the Tiñor collapse is displayed in the galerias (horizontal tunnels developed to mine groundwater) excavated in the El Golfo escarpment. At the end of one galeria, El Golfo lavas with normal polarity dated at 543ka occur at the same level as east dipping Tiñor lavas with reversed polarity dated at 1.03Ma (Carracedo *et al.* 1999,2001). There are no offshore debris avalanche deposits that can be identified with the Tiñor collapse; these appear to have been covered by the more recent El Golfo collapse deposits.

Giant lateral collapses are a common feature of the early stages of the subaeriel development of volcanic ocean islands. High cliffs and arcuate embayments similar to those on El Hierro, together with offshore debris avalanche deposits, have been identified for the other Canary Islands as well as other ocean island volcanoes including the Hawaiian islands and Reunion (Gee *et al.* 2001). However, El Hierro is unique in having an example of an aborted or incomplete collapse structure: the east flank of the island appears to be a detached fault block bounded to the west by the San Andres fault system (Carracedo *et al.* 2001). When this feature was first discovered there was some concern that it comprised an active incipient collapse structure, with the potential to be a major natural hazard. Subsequent studies have found Rift Series lavas dated at 145ka crossing the fault system without displacement. This indicates that the fault system is an old and inactive structure that was not reactivated during the more recent El Golfo collapse (Day *et al.* 1997).

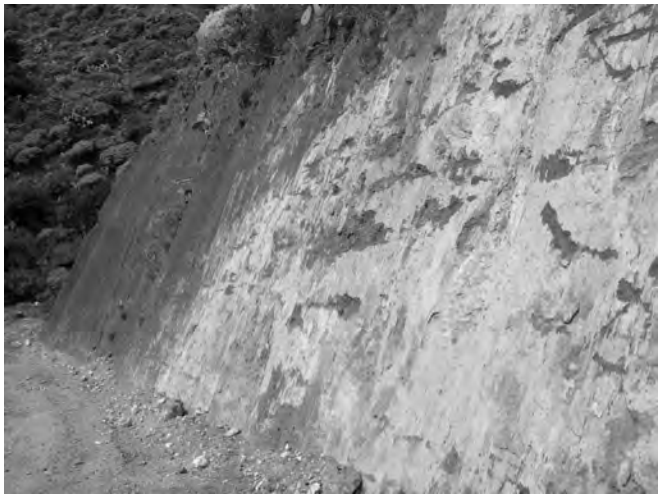

Figure 6. View of the San Andres fault surface exposed in a recent road cut in Barranco de Tiñor. The exposure is around 5 m high. Location: 27° 47.307' N 17° 55.273' W (WGS84 datum on GPS).

The San Andres fault system is intermittently exposed along its length. The best exposure is in the Barranco de Tiñor, where a 70m length of the fault plane is exposed in a recent road cut (Figure 6). Here the apparently fresh topographic fault scarp has been produced by the recent preferential erosion of the softer palaeoscree hanging wall deposits, which has exhumed the more resistant fault rocks on the footwall. This outstanding exposure is around 2.5km along a dirt track that branches off the main road (TF911) in the southern outskirts of Valverde. This track starts immediately to the south of a sports complex on the east side of the main road and there is plenty of room to park cars at the head of the track. Follow the track for around 1.3km, then take the right fork steeply downhill to the SW into the Barranco de Tiñor.

The exhumed fault surface is 5-10m high. Overall, the surface strikes 074° (magnetic) with a dip of 60° to the SE, although in detail the orientation of the surface is rather variable, comprising a number of open folds on a metre-scale wavelength. At the east end of the exposure, the strike swings round to 040° and the fault surface disappears into the hillside. The fault surface is truncated at the west end by a small gully: this provides a useful cross section through the footwall and shows very little deformation beyond 0.5m below the fault surface.

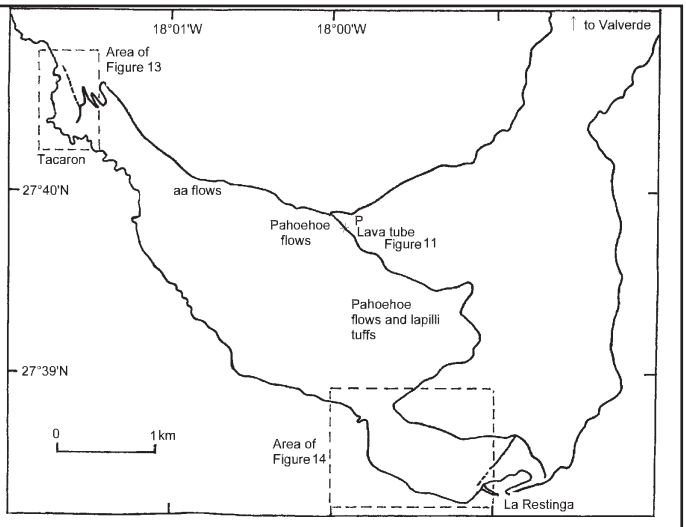

Figure 7. Location map for the SSE Rift volcanic area.

Figure 8. Leveed lava flow (flow c. 0.3m wide). Tacaron junction area.

The rocks immediately below the fault surface comprise a yellow-brown indurated breccia around 30cm thick with a 1-2cm thick greyish layer immediately below the fault surface. The latter layer appears to be impermeable to water, resulting in the deposition of white carbonate minerals on the fault surface and in the lowest rocks of the hanging wall.

SSE Rift volcanic area

The recent volcanism along the SSE rift is covered very briefly as part of Stop 9.21 in the recent field guide of Carracedo & Day (2002). This area has a wealth of volcanic features: the following section provides more details of this outstanding location. Figure 7 comprises an overview map of the area, most of which is sparsely vegetated.

The area around the junction between the main road from Valverde to La Restinga and the minor road to Tacaron is covered by a mix of aa and pahoehoe lava flows. The area across the road immediately north of the pull-in (P on Figure 7) has good examples of leveed flows (Figure 8), in one case showing extensive

Figure 9. Outwardly dipping lava sheets produced by a channelled lava flow overtopping the flow levees. The "overbank" flows extend for 2-5 m from the main channel. Tacaron junction area Location: 27° 39.899' N 17° 59.857' W (WGS84 datum on GPS).

Figure 10. Lava tumulus with fluid lava "squeeze out" from a medial crack. Tacaron junction area.

Figure 11. Lava tube in pahoehoe flow field cut by road . Tacaron junction area. Location: 27° 39.767' N 17° 59.947' W (WGS84 datum on GPS).

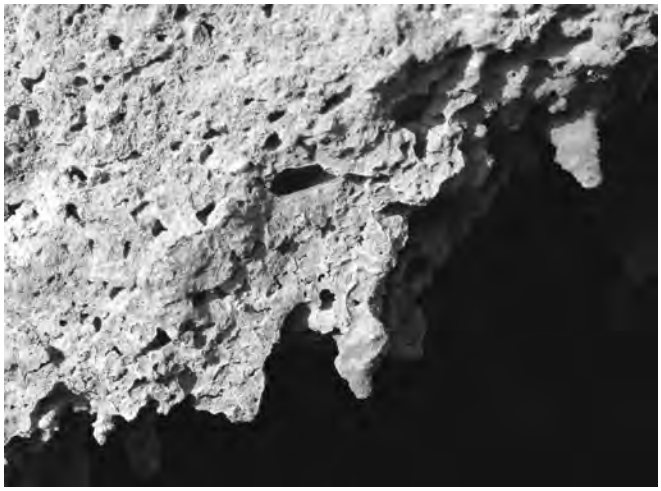

Figure 12. Lava "stalactites" on the roof of the lava tube shown in Figure 11. Largest "stalactite" *c.* 3cm long.

"overbank" sheet flows (Figure 9), lava tumuli with "squeeze outs" (Figure 10) and flows that are locally roofed over. The area contained within the bend of the main road has excellent examples of ropy pahoehoe surfaces. On the south side of this area, the road has cut through a lava tube, allowing examination of "lava stalactites" on the roof of the tube (Figures 11, 12).

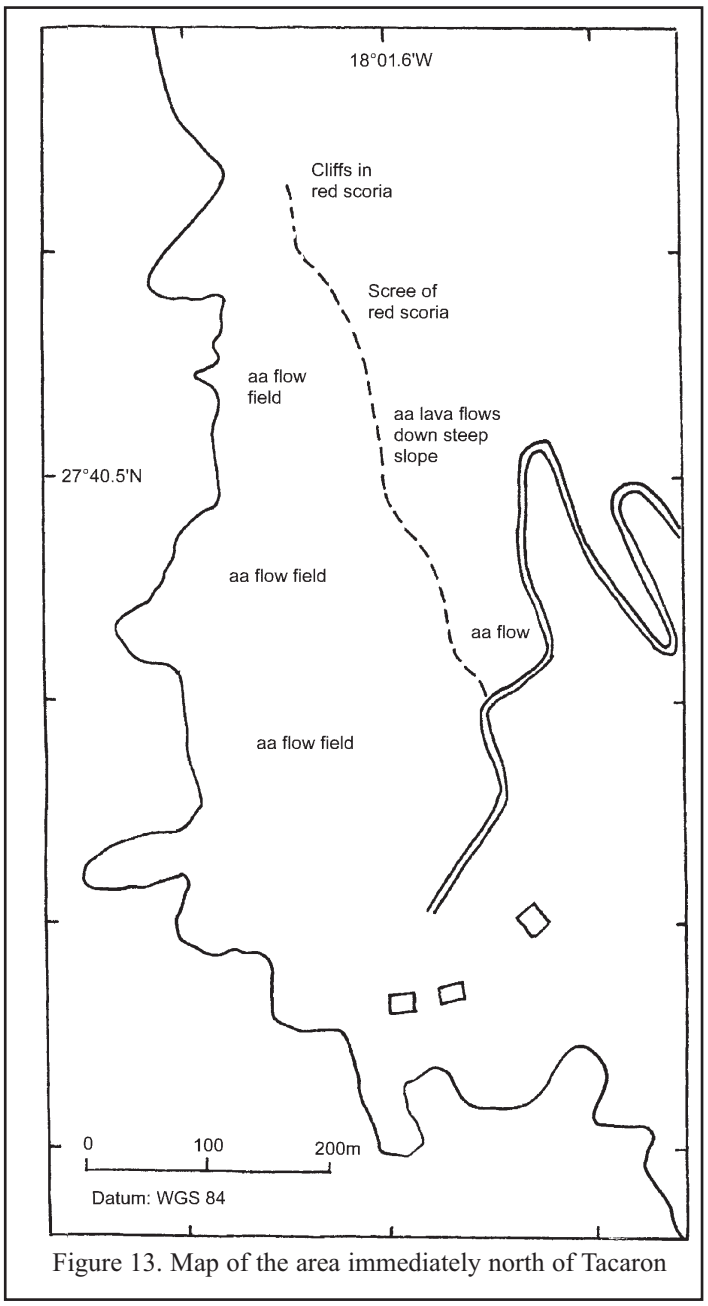

Figure 13. Map of the area immediately north of Tacaron

From the road junction, the minor road to Tacaron crosses a pahoehoe flow field and then enters an area dominated by aa flows. Figure 13 comprises a map of the coastal area immediately to the north of Tacaron, where aa flows can be seen descending the cliffs and flowing out onto the coastal plain. Cross sections through these flows can be examined in road cuts, where massive cores typically 1-4m thick can be seen sandwiched between rubbly tops and bases. In hand specimen the massive core material is dark grey, fine grained and vesicular, with conspicuous phenocrysts of fresh olivine up to 2mm.

Figure 14 shows a map of the area immediately west of La Restinga between the main road and the coast. The area immediately to the south of the road comprises a pahoehoe flow field with a variety of features, including lobate pahoehoe (Figure 15), folded pahoehoe (Figure 16) and lava tumuli (Figure 17). Nearer to the coast, the pahoehoe flows descend a discontinuous line of low cliffs where they develop "lavafalls" (Figure 18).

Much of the pahoehoe lava is vesicular and sparsely phyric, however around location 6 (Figure 14), an area of "bouldery" lava

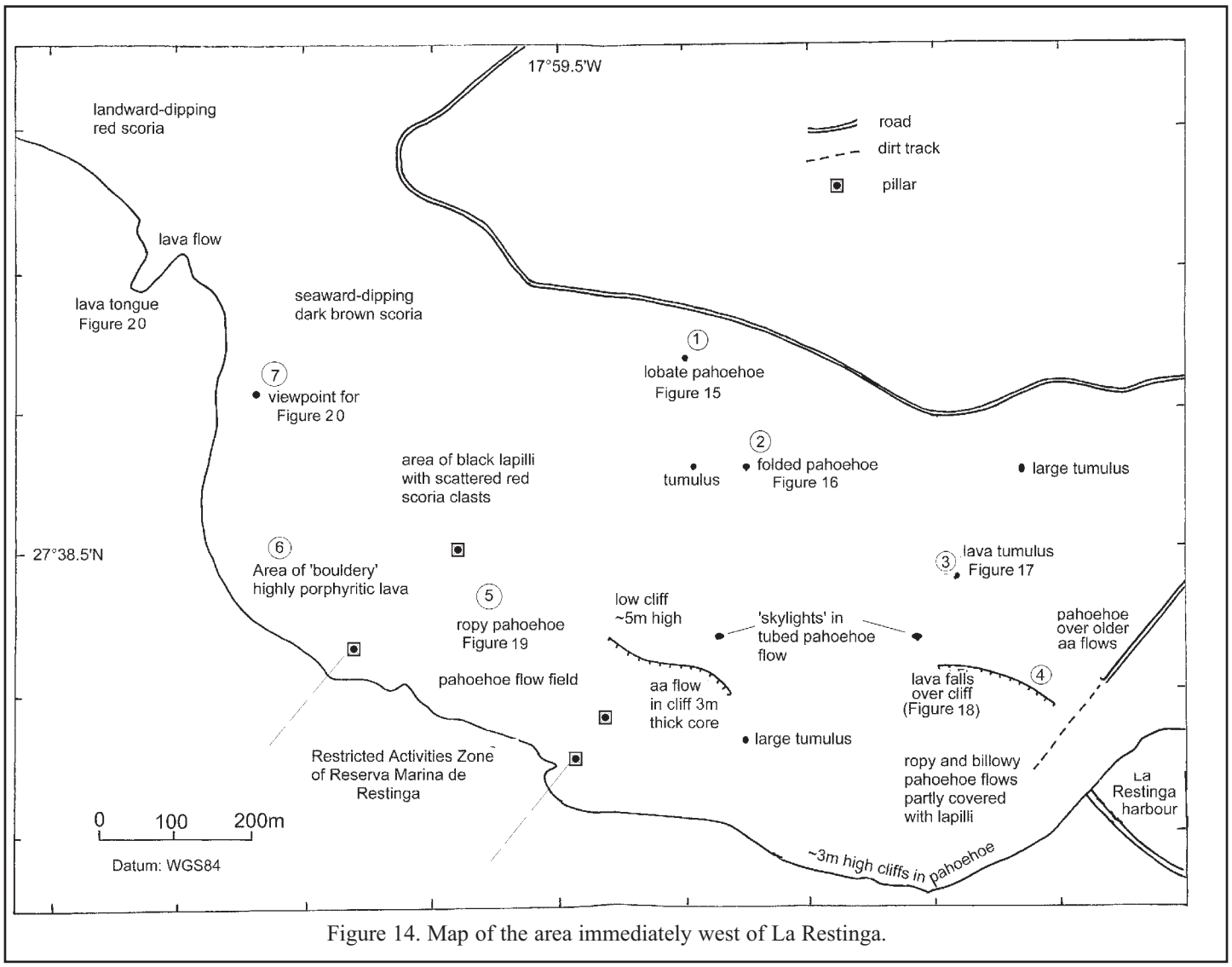

Figure 14. Map of the area immediately west of La Restinga.

comprises highly porphyritic basalt with olivine and pyroxene phenocrysts up to 10mm long. The pyroxene phenocrysts have a tendency to be more resistant to erosion than the olivine so good euhedral pyroxene crystals can be picked out of the surrounding lapilli.

Location 7 (Figure 14) is the furthest point NW accessible along the coast. From this location there is an excellent view west along the coastal cliffs, which are dominated by bedded pyroclastic sequences (Figure 20) cut by conspicuous vertical dykes. Immediately opposite location 7, the upper cliff contains a compound lava flow that appears to have flowed in a palaeovalley cut into the underlying pyroclasts. The compound flow consists of at least three separate flows, with the two lower flows separated by a well developed red weathering layer. The middle flow is thick

Figure 15. Lobate pahoehoe lava flow. La Restinga area. Location 1 on Figure 14.

Figure 16. Intricately folded surface of pahoehoe lava flow. La Restinga area. Location 2 on Figure 14.

Figure 17. Lava tumulus. The excess pressure of the fluid lava beneath the solid ropy pahoehoe crust has caused the surface to split and dome upwards. La Restinga area. Location 3 on Figure 14.

Figure 18. "Lava fall" where the pahoehoe flow descended steep cliffs. La Restinga area. Location 4 on Figure 14.

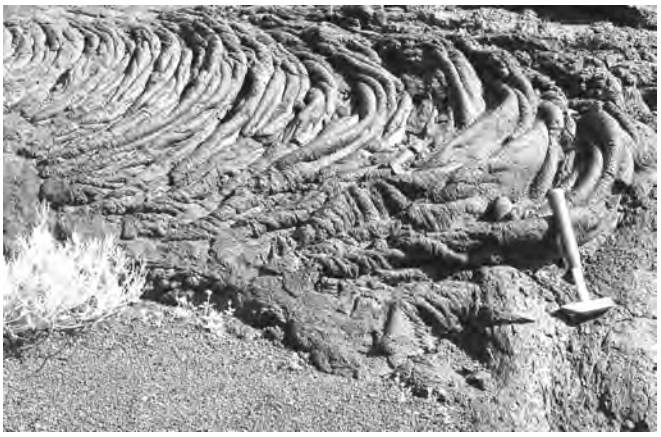

Figure 19. Ropy pahoehoe flow. La Restinga area. Location 5 on Figure 14.

with a massive core extending down to the base of the flow. The top lava flow appears to have plastered a thin skin of lava on the adjacent steep cliffs in the bedded pyroclastics. On the coast immediately south-west of this compound flow, a tongue of lava protrudes seawards for around 100m. It is probable that this feature was sourced by the compound lava flow above. Unfortunately this feature can only be reached from the sea. A report on the examination of this feature by a scuba-diving OUGS member, perhaps using the facilities of the nearby dive centre in La Restinga, is eagerly awaited.

Acknowledgements

I wish to thank El Director General del Medio Natural, Gobierno de Canarias for permission to collect rock samples on El Hierro.

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Figure 20. View NW from Location 7 on Figure 14. La Restinga area. Cliffs in bedded pyroclastics are cut by vertical dykes. The lava flow at the cliff top on the RHS has sourced the prominent tongue of lava protruding seawards in the centre of the photograph.

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Book reviews

The Pleistocene Boundary and the Beginning of the Quaternary edited by J. A. Van Couvering, 2004, Cambridge , 296pp, £38.00 (paperback) ISBN 0521617022.

This book or collection of papers really, describes in detail how a boundary between two periods of geological time is created by geologists.

The volume begins with a preface that gives a brief outline of the evolution and ideas involved in the formulation of this boundary, apparently the Pleistocene Boundary (the lower and only boundary of the Quaternary) was first mooted at the 16th International Geological Congress held in London in 1948, and the first edition of this volume released in 1997!

The main body of the book is divided into four sections that deal with the boundary in detail. The first section deals with the "definition of the base of the Quaternary". This is in fact the dreary but important part in which the threads are drawn together, allowing geologists in various fields to begin their work.

The second section explains the nuts and bolts of defining a boundary in terms of the stratotype location (Vrica, Calabria, Southern Italy), the various methods used, magnetostratigraphy, nanno and microfossils and the various sediments that make up the rocks found at the stratotype location and how these are used for correlation throughout the world.

The third section describes the paleontological context of the Pleistocene boundary, in terms of deep-sea sediments, "changes in late Cainozoic flora", mammal faunas found at the boundary and human evolution, the genus Homo made its first appearance close to this boundary.

The final section looks at the boundary as it is found throughout the world. This is quite a lengthy section but well worth paying attention to, as what was described earlier is expanded on. The Boundary if you wish to look for it in the UK is not well represented being present only in East Anglia and composed of the marine near-shore and estuarine shelly sands and clays of the Crag formations.

Is this volume worth a read? Well yes is the answer as it shows in quite detailed chapters the work involved in explaining what most of us would take as given, the Pleistocene/Quaternary is set as close to 1.8 Ma.

Chris Gleeson BSc Hons (Open)

Inventing the Earth: Ideas on Landscape Development Since 1740 by Barbara A Kennedy, 2006, Blackwell Publishing, 160 pages, £19.99 paperback, £50.00 hardback ISBN 1405101881 paperback, 1405101873 hardback

This book is a series of linked essays deriving from a lecture series given over the period 1973–1999 at the Universities of Manchester and Oxford. The object of the book is to try and show how contemporary "truths" have come to be accepted and the first chapter discusses scientific revolutions, drawing on the ideas of Kuhn and the nature of paradigms, and examining in particular the use of Chamberlin's Method of Multiple Working Hypotheses.

Chapter 2 covers the conflicting ideas of eighteenth and early nineteenth century scientists about the age and origin of the Earth. Chapter 3 entitled "Inventing Modern Earth Science" outlines the different theories about the origin of rocks, the widespread discussions about the causes of global topography and the evidence for changing relative levels of land and sea. This chapter also deals with Lyell and his great work The Principles of Geology.

There were conflicting ideas about the role of rain, rivers, ice and sea in creating landforms and Chapter 4 covers Agassiz's ideas about a massive Ice Age and the power of ice to mould the scenery. In Chapter 5 we read how Darwin used Lyell's Principles as a textbook on the Beagle voyage but that, unlike Lyell, he accepted Agassiz's ideas about land ice, and the significance of fluvial processes.

Chapter 6 covers the rôle of rain and rivers in the USA Southwest, and William Morris Davis is the subject of Chapter 7. He was an extremely influential Harvard Professor who invented "The Geographical Cycle" which explained the sequence of youthful, mature and old-age forms, culminating in the virtually flat peneplain. Chapter 8 deals with the rejection of these historical ideas and "the Reductionist Revolution, 1945-1977". The last chapter focuses on important shifts since 1977 in the way geomorphologists regard earth surface processes.

Appendix I gives an informative "Cast of Principal Characters" and Appendix II contains a very useful "Selective Glossary of Technical Terms". There are ten pages of References and a comprehensive Index.

The bias of the book is towards fluvial geomorphology, the author's own speciality, and most of the black and white illustrations are from original sources or the author's photographs.

Although the author says in the Preface "This is not a textbook on the History of Earth Sciences" it is a book that will appeal to anyone interested in the History of Science, dealing as it does with key moments in the development of ideas about the Earth.

Elizabeth Maddocks BA(Open)

Field Observations in the Lower Ordovician rocks of the North Pembrokeshire coast

John Downes

The coast of North Pembrokeshire is formed mainly of sediments and volcanics of Lower Ordovician age; namely the Arenig, Llanvirn and Llandeilo Series (Figure 1). The coastal outcrop of Lower Ordovician runs from Whitesands Bay, near St. David's Head, north-eastwards to Fishguard Bay (Figure 2). The NE -SW structural trend of the rocks is the result of the Caledonian earth movements, as is evidenced by structures such the St David's anticline and the Abereiddy syncline. All the following localities can be relatively easily accessed from the coastal path but it is best to visit Abereiddy at low tide if the graptolitic shales are to be examined on the foreshore.

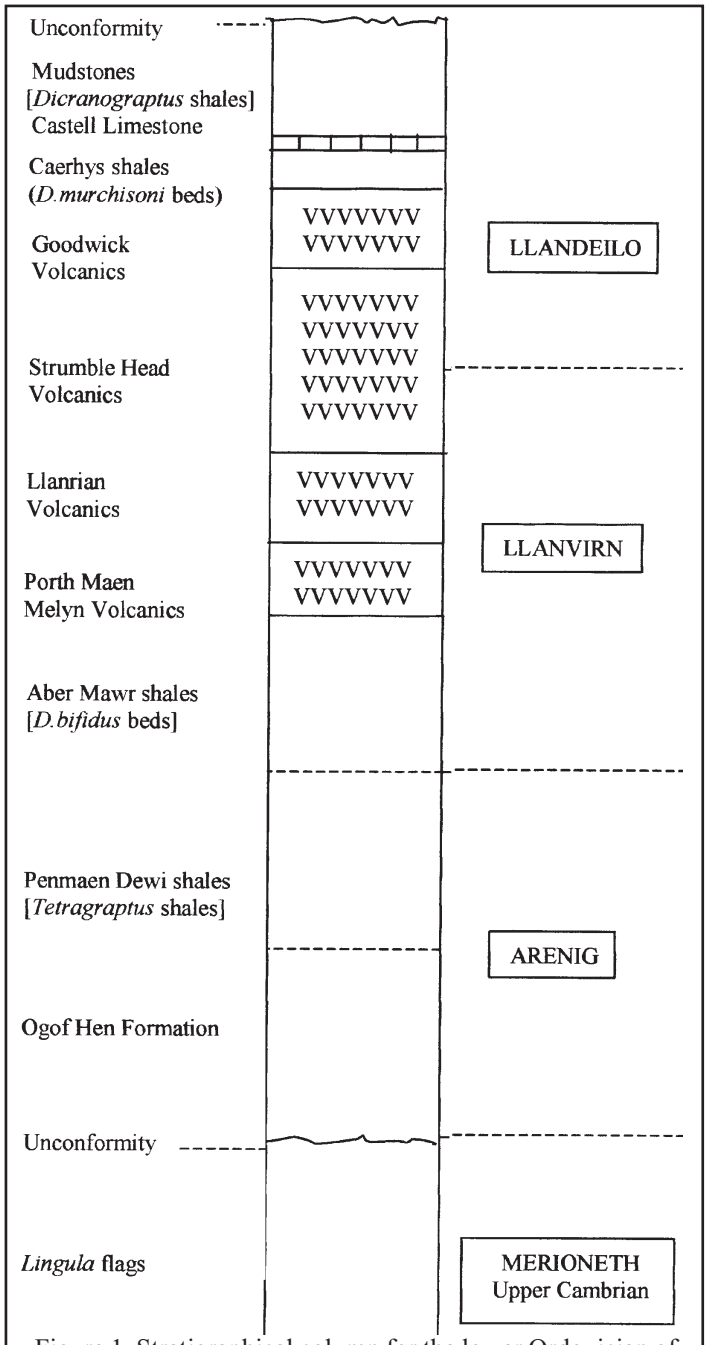

Figure 1. Stratigraphical column for the lower Ordovician of north Pembrokeshire.

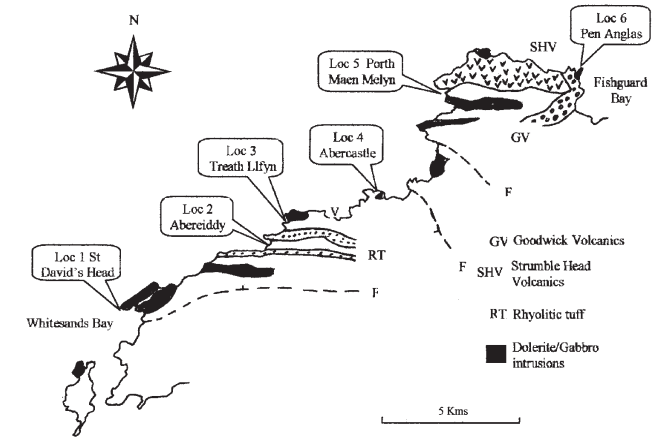

Figure 2. Outcrops of Ordovician igneous rocks in North Pembrokeshire.

1. St. David's Head (SM721279) can be approached from Whitesands Bay about 3kms to the NW of St. Davids. There is a large carpark near the beach which charges an entrance fee of £2.50 during the tourist season. From the carpark walk northwards along the coast towards Trwynhwrddyn (Ram's Nose); this headland is formed of the *Lingula* Flags of Upper Cambrian age (Merioneth series). (Figure 3) Here the strata are riddled with quartz veins in a fault shatter zone and these veins have strengthened the resistance of the headland to erosion. The beds include sandstones and shales that appear to represent a turbidite sequence. The sediments show graded bedding, flute casts, ripple lamination and slump structures. From the evidence of graded bedding in the sandstone, you should be able to work out the direction of younging in these steeply dipping beds. The shales contain the small dark-shelled brachiopod *Lingulella davisi;* this

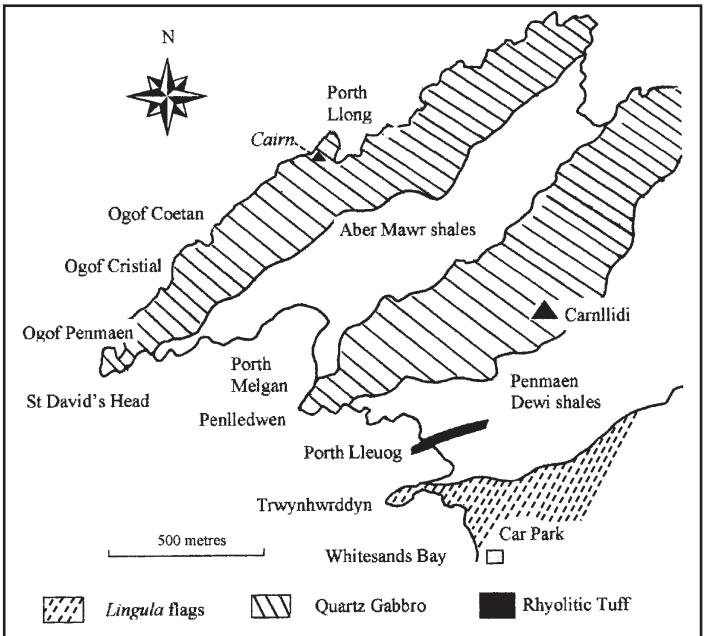

Figure 3. The geology of the area around St David's Head.

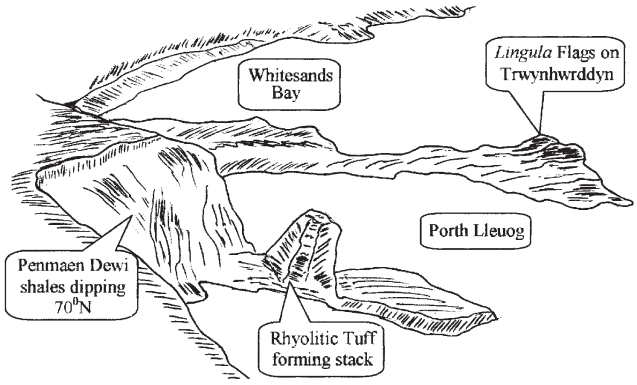

Figure 4. View south across Porth Lleuog.

is one of the first brachiopods to appear in the geological record. Remarkably this organism has changed little over the last 500 Ma and can still be found today as *Lingula* in the Sea of Japan.

North of Trwynhwrddyn one enters Porth Lleuog (Figure 4) where the strongly cleaved Penmaen Dewi shales (Arenig age) are exposed with a dip of 70°N. These beds are faulted against the underlying *Lingula* Flags; they contain rare specimens of the dendroid graptolite *Dictyonema* and the four-stiped *Tetragraptus*. About half way across the bay there is a 50m thick band of rhyolitic tuff outcropping on the foreshore; this resistant volcaniclastic bed is concordant with the steep dip of the shales.

The next headland is Penlledwen, formed by the quartz gabbro intrusion of Carnllidi. The junction between the baked Aber Mawr shales (Llanvirn) and the gabbro intrusion can be seen near the footpath on the headland. Continue along the path down to Porth Melgan which is cut into the less resistant shales. There are several large boulders of pegmatic gabbro on the foreshore with fresh faces which display well-shaped pyroxene and plagioclase crystals. Next follow the coast path towards St David's Head crossing the baked shales along the southern margin of the St David's quartz gabbro intrusion. The gabbro intrusions appear to have been emplaced conformably into the Lower Ordovician sediments. The Carnllidi gabbro dips steeply to the NW whilst the St David's gabbro dips steeply to the SE suggesting that they may be linked at depth. These intrusions are between 335 - 396m thick and are flanked by hornfelsed sediments forming a baked zone some 60m thick. The gabbros are composite differentiated sheets that are zoned parallel to the Caledonian trend of the intrusions.

The crags on the St David's headland clearly illustrate the NE-SW strike direction of the jointed gabbro and careful examination of the blocks will show that there are numerous narrow felsic segregation bands orientated parallel to the strike. Walk over the rocks to the NW side of the headland and then proceed carefully down to the deep inlet of Ogof Penmaen, crossing over the narrow rock causeway to the western extremity of the headland. The view NE across the inlet reveals a rock face cut by mafic-felsic segregation bands that follow the strike of the intrusion. These bands are up to 50mm thick and represent the separation of mafic melt from felsic-rich mineral zones.

The next major inlet is Ogof Cristial where one should descend about half way down the cliffs to where the quartz gabbro grades southwards into leucogabbro (a gabbro rich in felsic minerals) that is interbanded with fluxion quartz gabbro. The latter can be recognised by the sub-parallel orientation of the elongate plagioclase crystals. Proceed about 100m NW to Ogof Coetan which is overlooked by the Bronze Age burial chamber of Authur's Quoit. Descend the SE side of the inlet where the fluxion quartz gabbro is in irregular contact with a zone of dark rusty brown magnetite gabbro.

Follow the track heading upwards to Carn Porth Llong passing the head of Llechcenhinen inlet; fluxion gabbros are exposed in many places where the path has been eroded. On reaching the cairn, walk due south for about 50m to examine the crags formed of pegmatitic gabbro. Note that there is a general coarsening of rock texture towards the centre of the intrusion where the pegmatitic facies is developed. This is due to the slower cooling rate within the centre of the intrusion where there are some blocks containing prismatic pyroxene crystals up to 12mm long. Here the segregation of mafic and felsic minerals has produced light and dark patches within the pegmatitic gabbro.

Return to the cairn and then traverse NE to the cliffs overlooking Porth Llong. The view along the coast clearly shows bands of dark weathered magnetite gabbro alternating with light-coloured quartz gabbro along the strike of the intrusion. From this locality follow the track leading south to Porth Melgan where the coastal route can be rejoined for the return journey to the carpark.

2. Abereiddy Bay (SM796313) can be reached from Croes Goch village on the A487 (Fishguard road) by following the signposted minor road for about 3 kms down to the coast. Parking facilities are provided near to the beach. Abereiddy Bay is eroded along the E-W axis of a syncline (Figure 5) developed in the mudstones of Llanvirn and Llandeilo age that are rich in graptolitic remains. The high fossilisation potential of these organisms in this locality is largely due to the fact that the bedding planes of the strata coincide with the direction of cleavage. This means that the organic remains were not destroyed during the Caledonian earth movements which folded the rocks, since the cleavage was imposed parallel to the bedding rather than at an angle to it. The Aber Mawr shales (Llanvirn) contain the tuning fork graptolite *Didymograptus bifidus* recognised by two stipes hanging downwards; whilst in the higher Caerhys beds (Llandeilo) there is the larger *Didymograptus murchisoni*. The Aber Mawr shales are not exposed on the south side of the bay although they do outcrop further along the coast to the west. The *Murchisoni* ash band also known as the Abereiddy tuff (Llanrian Volcanics) forms the cliffs along the southern edge of the bay consisting of a coarse pumiceous lapilli tuff. The succeeding Caerhys beds

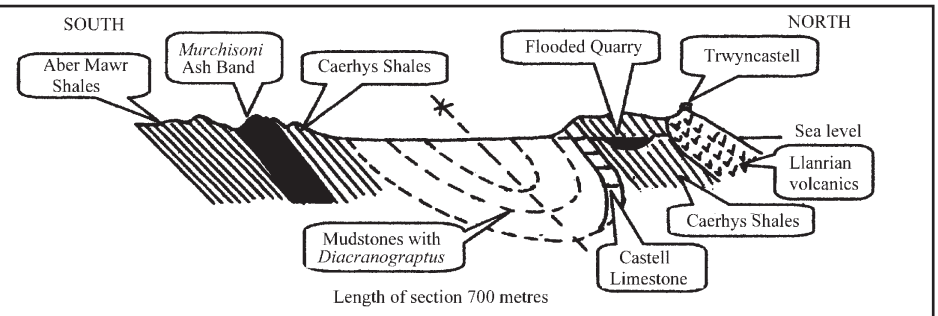

Figure 5. Geological section across Abereiddy Bay.

can best be examined in the SW corner of the bay near to some large boulders. Here specimens of *D. murchisoni* are present on the bedding planes. The same bed is also exposed in the road cutting opposite a small T junction (SM796311) where the lane from Caerhys village joins the Abereiddy road.

By walking northwards around the bay one crosses the axis of the syncline where undifferentiated dark grey mudstones (Llandeilo) containing *Dicranograptus* can be seen in the cliffs. Note that the beds are becoming increasingly older as we move away from synclinal axis. Continue along the foreshore to the Trwyncastell headland where the disused slate quarry is now flooded by sea water. The Castell limestone outcrops at the quarry entrance where it is faulted against the Caerhys beds. The scree material in the quarry yields a fauna of didymograptids, brachiopods, and trilobites. The beds dip at 70°N but they form the inverted limb of the Abereiddy syncline. Load casts can be seen on the inverted bedding plane beneath the small bridge at the entrance to the quarry. Note that the headlands on either side of Abereiddy Bay are formed of resistant rhyolitic tuffs of the Llanrian Volcanic Formation. These pyroclastics were erupted from volcanoes on the southern margin of the Iapetus ocean where large amounts of graptolitic mudstones were being deposited in a subsiding basin.

3.Treath Llfyn (SM803320) is the next beach north of Abereiddy and it can best be approached by following the track over the Trwyncastell headland from the carpark at Abereiddy. Whilst crossing to the north side of the headland, note that the rhyolitic tuffs of the Llanrian Volcanic Formation are intruded by a thick band of E-W trending gabbro that outcrops on Carn Llwyd (SM798317). Descend to beach level by the steps in the middle of the bay and make for the south side of Treath Llfyn where the basal tuffs dip at 80°N. Here the tuffs form the north side of the Abereiddy syncline hence they are inverted. Several of the lighter-coloured beds of coarse ash contain lapilli ranging in diameter from 1-6cm. The junction between the rhyolitic tuffs and the Aber Mawr shales can be seen in the SE corner of the bay, but walking back towards the steps the shales become deformed and crushed. A nodular tuff occurs just south of the steps but a thicker tuff unit crosses the northern part of the beach; this has a distinctive erosional base (north side) and a sharp contact with the shales (Figure 6). There are several graded beds showing an overall fining upwards sequence indicative of an air fall deposit. The northern headland is composed of an elongated gabbro intrusion which separates Treath Llfyn from the next small bay known as Porth Egr where the Penmaen Dewi shales (formerly known as the *Tetragraptus* shales) are exposed on the foreshore. Here they

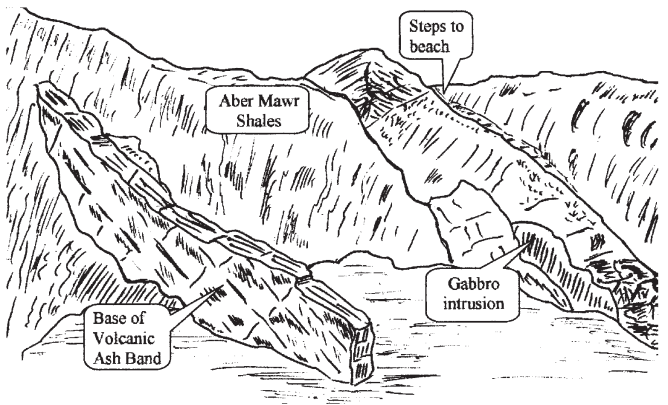

Figure 6. Treath Llfyn - north side.

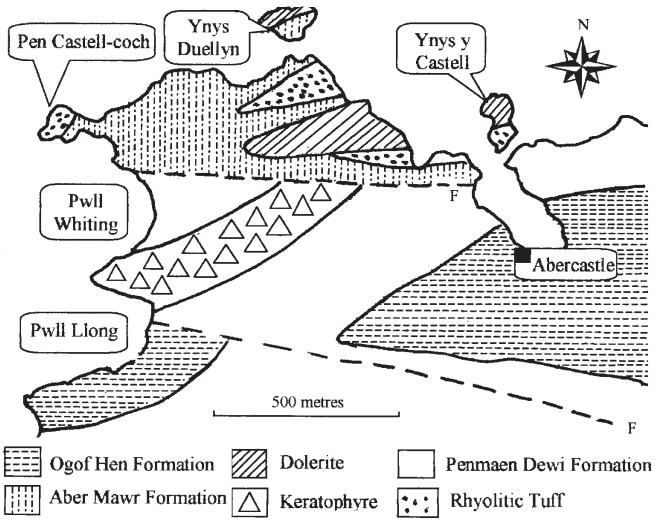

Figure 7. Geology of the Abercastle area.

are seen to grade laterally into the sandy shales of the Ogof Hen Formation. The latter contains a distinctive 30cm-thick basal conglomerate that forms the southern edge of the Pen Porth Egr headland. The conglomerate is faulted against the cross-bedded quartzites and interbedded shales of the *Lingula* Flags (Upper Cambrian) which display several minor folds on the extreme SW tip of the headland.

From Porth Egr one can continue along the coast to Porthgain where refreshments can be taken at the Sloop Inn. This village still retains its 19th century industrial heritage in the form of huge brick-built hoppers which were used to store crushed dolerite used as roadstone. The rock was quarried on the headland to the west of the village and brought down by a rail to the crushers. The material was shipped out of Porthgain harbour up until the 1930s when economic decline forced operations to cease.

4. Abercastle (SM853336) is a small fishing village that can be reached by taking the minor road through Trefin from the Square and Compass Inn on the A487. There is a small carpark alongside the slipway. Follow the coast path on the west side of the estuary. In several places the track is cut through outcrops of the Penmaen Dewi shales which display strong cleavage dipping about 70°NE. Follow the path up on to the headland until you are opposite Ynys y Castell (Figure 7). The north side of this island displays a large dolerite intrusion cross-cutting bedded rhyolitic tuffs. Continue along the path towards Ynys Duellyn where the Aber Mawr shales

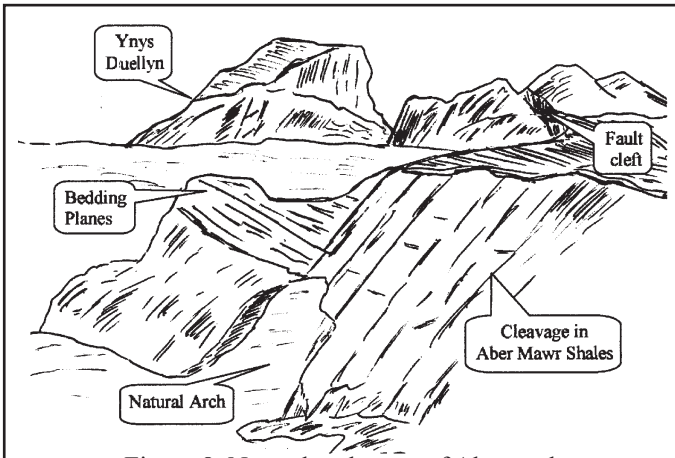

Figure 8. Natural arch west of Abercastle.

are well exposed in the steep sided faulted cleft that separates the island from the mainland. However they form a spectacular natural arch (Figure 8) about 300m along the coast to the west where the cleavage planes are dipping steeply NW but the bedding planes can clearly be seen above the arch dipping at about 30°SE. The next headland is Pen Castell-coch, the site of an Iron Age encampment. The headland itself is composed of rhyolitic tuffs that can be well seen in the west-facing cliffs, where they contain almost vertical beds of coarse lapilli separated by ash bands. Walk around Pwll Whiting to the promontory on the south side which is formed of a vertically bedded keratophyre lava flow. This rock is rich in sodium plagioclase feldspar (albite) and is produced by the alteration of intermediate volcanic lavas. Beyond the keratophyre outcrop are the cliffs of massive grey sandstones and conglomerates of the Ogof Hen Formation, which are the lowest Ordovician beds outcropping on the south side of Pwll Llong. One can return to Abercastle either by following the coastal path or by taking the footpath from Pwll Llong to the Trefin - Abercastle road.

5. Porth Maen Melyn (SM889393) is a small inlet on the coast south of Strumble Head. It is approached from the A487 Fishguard road by taking the minor road to St Nicholas and thence to the coast at Pwll Deri. There is a small carparking area on the east side of the road (SM892388) which is cut out of the Penmaen Dewi shales (Arenig age) (Figure 9). Walk down the track leading to the youth hostel and descend to Dinas Mawr (SM888386) which is a headland formed of sill type intrusion of microtonalite; an igneous rock rich in plagioclase and quartz. Follow the coast path in a northerly direction crossing another outcrop of the Penmaen Dewi Formation (cleaved mudstones) before reaching the dolerite intrusion of Garn Fawr (213m) which is exposed on

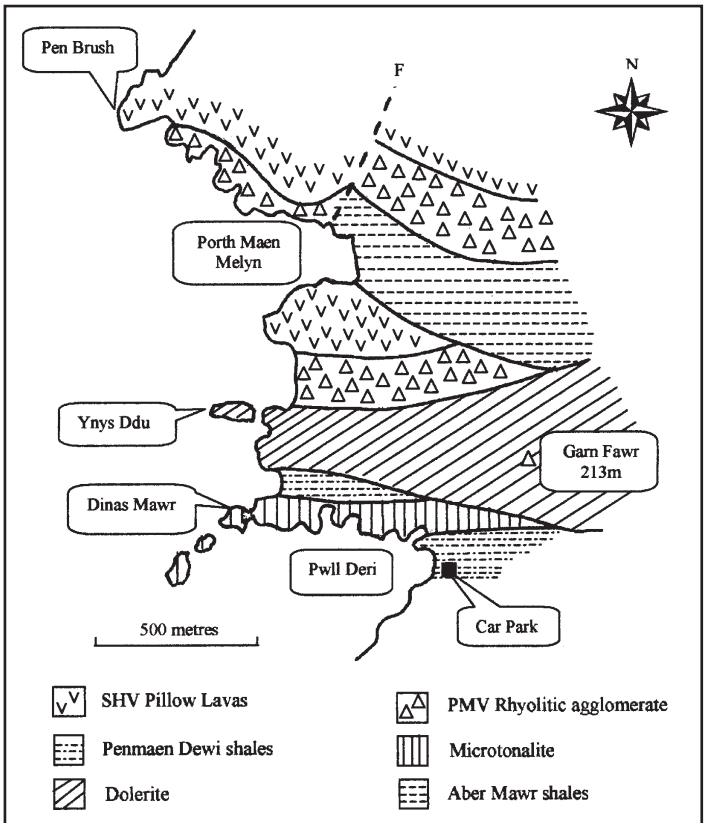

Figure 9. map of the geology or Porth Maen Melyn.

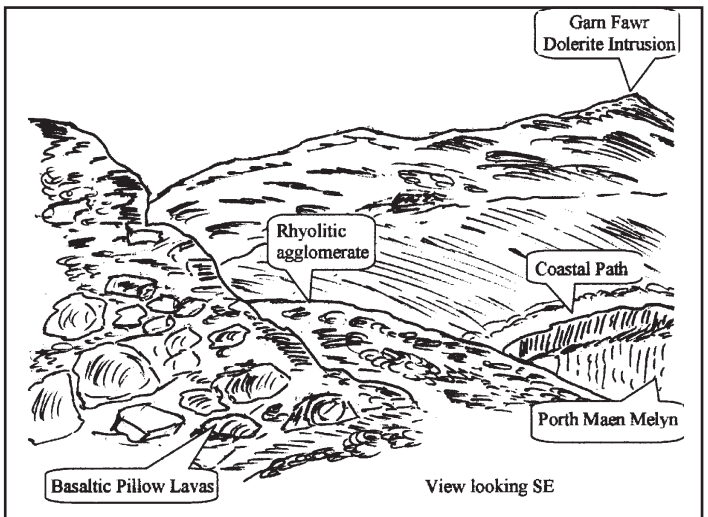

Figure 10. Pillow lavas at Porth Maen Melyn.

the coast opposite Ynys Ddu (SM888388). Continue along the path to Porth Maen Melyn, a bay excavated in the Aber Mawr shales. On the north side of the bay the crags to the west of the path are formed of agglomerates with angular clasts of rhyolite set in a crystal-rich matrix. These brecciated rocks probably represent the pyroclastic deposits produced by a volcano rising from the sea in Llanvirn times. Certainly some of the lava flows would have been underwater as indicated by the pillow lavas which outcrop in the crags at the top of the slope beyond the wall (Figure 10). These lavas belong to the Strumble Head Series and they are well exposed and accessible on the cliff top. They display the characteristic features of submarine basalt flows with pillow structure, glassy reaction rims and former gas-filled vesicles. Epidote and quartz veins are common.

6. Pen Anglas (SM949405) is a headland on the extreme NE corner of the Pen Caer peninsula. It can be accessed from Goodwick by driving up New Hill to Harbour Village where a small carpark (SM948389) is situated behind the last row of houses. Take the track past the Neolithic cromlechs of Garn Wen and join the coastal path which starts at the northern end of Harbour village. Follow the track as far as Crincoed (SM948399) then leave the main path and bear right towards Pen Anglas; following the narrow path to the first beacon which is a thick wooden pole on a concrete base. Continue along the line of the stumps of several

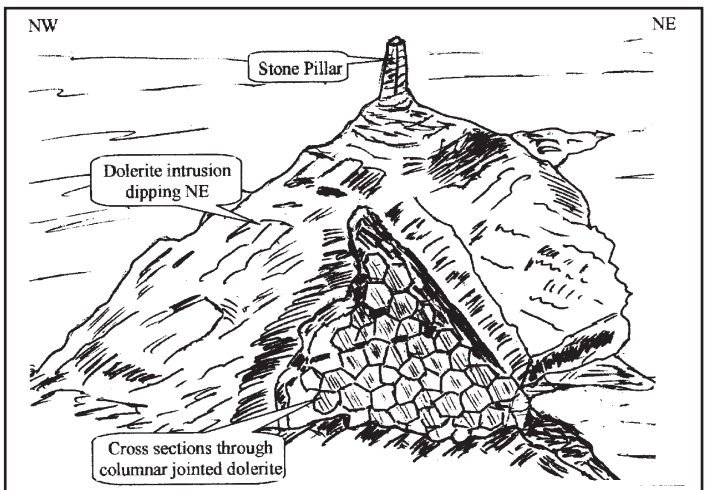

Figure 11. Pan Anglas headland.

more beacons leading down to the headland itself. Pen Anglas is formed of a dolerite intrusion and on the NE facing cliffs below the stone pillar, there are some excellent examples of columnar jointing (Figure 11). This inclined rock face shows sections through the columns demonstrating the polygonal cooling joints. Climb over the ridge to the SW side of the headland where the long axes of the columns can be seen. The whole intrusion therefore appears to be dipping at about 45° towards the NE where the upper surface is exposed.

Walk around Pen Anglas Bay to Y Penrhyn where rhyolitic breccias of the Goodwick Volcanic Formation are exposed. These are autobrecciated lavas which are thought to have been formed on the flanks of thick viscous felsic lava flows or domes where the congealed crust was fragmented by movement of the molten lava in the interior. The term agglomerate or volcanic breccia can be applied to these rocks which are composed almost entirely of rhyolitic clasts set in a rhyolitic matrix. Flow banding and flow folds also occur in the rhyolites on the west side of Y Penrhyn but care should be taken when descending the steep grassy slopes down to the outcrops. Further exposures of the rhyolitic lavas can be seen on Penfathach which is the next promontory along the coast to the west.

Maps

Geological Survey, 1:50,000, Sheet 209, St David's.

Gelogical Survey, 1:25,000, Sheet SM72, St David's.

Ordnance Survey, 1:25,000, Outdoor Leisure Sheet 35, North Pembrokeshire.

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Author

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Book reviews

Physical Processes in Earth and Environmental Sciences by Mike Leeder & Marta Perez-Arlucea, 2006, Blackwell Publishing, pp321, £24.99 (paperback) ISBN 1405101733.

In the introduction to his "Exposition du systeme du monde", Laplace wrote: " Infinitely varied in its effects, nature is simple only in its causes and its economy consists in producing a great number of phenomena, often very complicated, by means of a small number of general laws."

Leeder & Perez-Arlucea's book provides an introduction to these "general laws" by explaining the fundamental physical principles that help us to understand the workings of the Earth system.

The book is split into six chapters. The first two chapters are relatively short; they provide an introduction to the Earth system, heat & temperature, states of matter and kinematics. The following two chapters, "Forces and dynamics" and "Flow, deformation and transport", comprise 162 pages on the mechanics of solids and fluids. By the end of this you will have a good understanding of such topics as vorticity, Coriolis force, the stress ellipse and sediment transport. Don't try to read this section in one sitting! The final two chapters build on this foundation to look at "Inner earth processes and systems" (melting, magmas and volcanism) and "Outer earth processes and systems" (atmosphere, oceans and their interactions).

The book covers a lot of material, but avoids excessive mathematics. Many of the concepts are clearly related to examples or to everyday experience, so the reader is never lost in a maze of abstract ideas. The book is very well illustrated and one could learn a lot just by studying the figures and their captions. Unfortunately this otherwise excellent book is marred by a large number of errors that should have been corrected before publication. While many of these are trivial, some have the potential to mislead and cause confusion. A revised, corrected edition of this book will be an excellent addition to the bookshelves of any OU student with an interest in the fundamental physical processes of Earth Sciences.

Duncan Woodcock MA(Cantab), BSc Hons (Open).
Continuing (life long!) ES student.

China clay a geologist's view by Colin Bristow, 2006, Cornish Hillside Publications, 60pp, £7.99 (paperback) ISBN 1900147459.

China clay, or kaolin, is amazing stuff with many uses! Originally used for porcelain manufacture in China over 1000 years ago it has important industrial uses today. Colin Bristow, who was chief geologist with English China Clays in the pre-Imerys days, is one of the most well known authorities on Cornish china clay.

His new book on this subject has been timed to coincide with the opening of the Boulder Park at the Wheal Martyn SSSI, next to the well known China Clay Country Park. The Boulder Park contains examples of the different rock types found in china clay pits and Professor Bristow's book is aimed at people whose curiosity about this important Cornish industry has been whetted, perhaps by a visit to Wheal Martyn Country Park. It deals with the sort of questions they may ask: what is china clay and how was it formed? How are deposits found and are there any in other parts of the world? What minerals and rocks are found in clay pits and, importantly, what is the future of the industry and what environmental impact does it have?

The book is plentifully illustrated in B&W and colour, with many useful diagrams (some from the author's 'Cornwall's Geology and Scenery' also published by Cornish Hillside Publications). The author starts by discussing the nature of china clay, and the minerals and rocks associated with it, and puts it into context in the setting of SW England. The second part of the book includes sections on environmental concerns (older readers will remember the 'Cornish Alps'!) as well as the future of china clay and concludes with a section on china clay deposits in Europe and the rest of the world.

Moderately technical language in places will mean that a reader with no prior knowledge of geology or science might want to check out some terms in a suitable dictionary but they will, at the same time, learn a lot about this industry where Cornwall once dominated the western world and which is still Britain's second most important mineral export, after petroleum.

So, for visitors to Cornwall, and local people as well, this is a useful book which will add to your store of background knowledge about the region. If, after reading it, you still want to know more, then there is a useful reading list included.

Linda Fowler OU tutor

Walk along the Southern Strand: London Branch field trip along the South Bank of the River Thames 21 July 2005

Diana Clements geological aspect, J. Edwin Jarvis archaeological aspect, Adrian Rundle biological aspect

Introduction and the geological aspect

Normally in July, London Branch take to the streets on a building-stone walk instead of their usual monthly talk. In 2005 our original plans fell through and as a low spring tide was scheduled for 9pm on 21 July, this seemed an excellent opportunity to explore one of our few 'exposures' in Central London. This was a self-led walk along the 'Southern Strand' with the aim of looking at anything of interest. We are fortunate that one of our members, John Jarvis, is primarily an archaeologist so he was able to provide useful guidance. We were also lucky to co-opt Adrian Rundle, chairman of the Kent Geology Group, who works in the Natural History Museum. He is not only an expert on general fossil identification but is also extremely knowledgeable about the living animals that we were likely to come across.

The tide was only just low enough when we set off; nevertheless we were able to observe some interesting principles. The first concerned the sand placed in front of the Royal Festival Hall for the 1951 Festival of Britain Celebrations: it is still there, on the inside of the bend! So, London has a beach, fit for sandcastles that can be enjoyed at nearly every low tide, which demonstrates neatly how slack the velocity can be even in a tidal environment. The second was the distribution of grain size with fine at the top of the 'strand' and larger at low water – the reverse of what you would expect on a marine beach. Then there were definite strand lines picking up different aspects. These were particularly apparent at the end of our walk, on the large area of beach beneath the Oxo Tower. Here the uppermost strand lines were picked out by rows of charcoal and lighter elements including used rubber gloves and other similar, unsavoury items as well as some good crab carapaces. The next was rich in gastropod shells. It would be well worth making a detailed taphonomic study of these strand lines as a model for interpreting more ancient strata. Nearer the low-water level we found two separate horizons of in situ sandy clay which Adrian was able to sample and thereby provide faunal lists and draw some conclusions about the fauna (see below). Here we also found a few live animals.

Unexpectedly a couple of fossils turned up. The first was a small circular sponge preserved in flint from the Upper Chalk *Porosphaera globularia.* After the initial sandy stretch gravels were common underfoot. By far the majority of clasts were flint. This was not surprising as the Thames cuts through the Chalk upstream at the edge of the London Basin on its way to the sea, releasing the flint. More surprising was a large quantity of rounded chalk pebbles which were also there a few years ago when I started walking the Strand. Like the imported sand, they appeared relatively static. In a fully marine environment they would have been quickly eroded. There were also a number of large, barely rounded blocks of grey limestone which could have been Carboniferous. While we were examining these one of our members came up with our prize fossil find. This was a root section, *Stigmaria* of the Carboniferous lycopod 'tree' *Lepidodendron*. This fitted in nicely with our identification of the blocks but highlights the danger of trying to interpret the rock-types found within this Inner City stretch where building materials have been imported for over 2000 years. John Jarvis sheds some light on why we should find both the chalk and the blocks (see below).

The Thames has been flowing approximately along its present course only since the retreat of the glaciers at the end of the most extensive of the Ice Ages, the Anglian glaciation, some 400,000 years ago. Before then it is thought to have followed the present course of the Colne northwards. There is glacial till as far south as Finchley and a large pro-glacial lake centred on the Colne area burst its banks and pushed the route of the Thames further south, more or less along its present course. The Colne is now a tributary flowing south to join the Thames at Staines. Successive ice ages have left their mark in the gravels bordering the Thames, these are mostly of flint, the oldest at the top deposited when the river was braided, following a wide river plain. Gradually the Thames has cut its valley leaving a series of terraces. These have been crucial to the availability of water in early days and continue to be an important source of construction material. During Roman times the Thames was still shallow enough to ford at low tide. Only after the Great Stink of 1858 was a decision made to channel it. Joseph Bazalgette was commissioned to undertake this epic task (as well as installing London's sewer system) and for the time being it and the Thames Barrier protect London from the flooding so common in earlier times.

Quaternary fossils are relatively common in the gravels with both cold- and warm-environment species turning up in excavations from time to time. Unfortunately on this occasion we found none, although more recent bones were a common feature of the strand line. Some of our most interesting finds are listed below.

It was an interesting, if somewhat eerie, walk which we plan to continue in July 2006. It was the day of the failed bombings in London leaving transport very disrupted. Amazingly about 15 members managed to get there. London was uncannily quiet except for a large amount of police activity up and down the river. In 2006 we will walk eastwards around the Southwark area where there are reports of a fossil forest. Let us hope this time it will be unaccompanied by speeding police craft. (DC)

The archaeological aspect

With the geological and biological aspects being explained by other members it is here that only the historical and archaeological matters are considered. The meeting commenced late, due to disruptions by 'terrorist' activities to the London transport network. Assembly was at the Festival Pier in front of the Royal Festival Hall on the south bank of the River Thames. Dropping to the foreshore the group landed on sands that were residual of the deposits placed there for the 1951 Festival celebrations, so already we saw historical evidence underfoot.

As the party progressed eastward scrutinising the flotsam and jetsam littering the shore by the edge of a receding tide explanation was given to those at the head of an elongating group as to the archaeological implications in respect of the stretch of the river

from the G.L.C. Flood Barrier to the east at Woolwich to upriver at Richmond. First was consideration of the Authorities concerned with river bed ownership and legalities. Two authorities hold legal sway; one being the Port of London Authority the other being the Crown Estate. That the public may walk upon the foreshore is allowed, but digging or disturbance to the beds are governed by various laws - and this means that digging is not permitted without the relevant licence. These are given to approved individuals ranging from members of the 'Mudlarkers Society', to museum and Government employees - who have differing rules applied, such as to the depth of excavation allowed (from three inches to three metres). Granting of specific circumstances are to be had on an individual consideration - an illustration being the activities such as the 'Time Team' at Lambeth. A second consideration was also that there exists private land as with the Bridewell Estate Foreshore at Wapping on the north bank and the G.L.C. Foreshore at Waterloo Bridge on the south bank. Areas excluded from 'digging permit' activities apply on the north bank from Tower Bridge westward to the Victoria Tower Gardens at Westminster bridge. The other area where any form of disturbance is not allowed is that of Queenhithe Docks which is designated a 'Graded Listed Monument' (Monument 118A). The reasons for protection of the environment in the river environs cover matters such as prehistoric, Roman and later finds - timber structures, skulls, skeletons, important artefacts (flint, metal or organic) - and so dictate control of digging activities, where all finds are reported to the Museum of London for conservation and record purposes.

Having then outlined the rulings applying to the ground that the group was traversing, attention was paid to the small finds picked up by members. Clay pipe stem and bowl fragments evoked interest - especially where makers' marks were shown, and a variety of dates were in evidence from the seventeenth century to the nineteenth. Post mediaeval pottery and glass shard specimens were collected, as well as current debris that formed the surface of an accumulating bed to the deposits already formed. This layer receives constant attention from the daily classes of schoolchildren and individuals that permanently scan the beach, which results in little new material remaining unobserved. However, it is unpredictable as to what new items may be washed up by the tide so the exercise does not prove fruitless.

The furthermost point which the leading members reached before re-joining the group was Gabriels Wharf, by the OXO Building, west of Blackfriars Bridge. Here was seen the more interesting aspect of the archaeological evidence being laid down. Material from the dismantling of various ships, shown by such as metallic 'clench' material that had held ships' timbers together were met in patches, and still 'in situ' fine upright planking was being covered by the accumulating shingle. More robust planks were to be seen and these were derived from similar jetty structures to those still extant. Rolled blocks of chalk had been seen on the beach, which had been a puzzle to some members as to their origin. Upon inspection it was shown that these had originated from the core packing of the jetty structure still in place. Above this chalk infill was a layer of 'cinder' blocks which underlay a very fine capping of dressed blocks. An eroded 'hard' standing was also to be seen where the cinder blocks lay in disarray, yet the leading edge of dressed stone blocks lay in a reasonably well defined edge. Both jetty and hard showed fine examples of industrial archaeology in process of disintegration and preservation.

The most interesting examples of non-portable archaeology were to be found in the basal units employed to hold the chains for mooring small river craft. Two examples were seen (Figure 1). One was of a block of timber 1.2 metre x 40 cm, and an unknown thickness with the remnant chain still attached, the other a granite block with the rusted chain set centrally. Dating of these items was not to be had, but by the form of chain held to be 'Victorian'

Time went by swiftly, so at this point the group regrouped for a debriefing of all aspects - biological, geological and historical and at 9 p.m. all dispersed; some onto a very disjointed transport network. (JEJ)

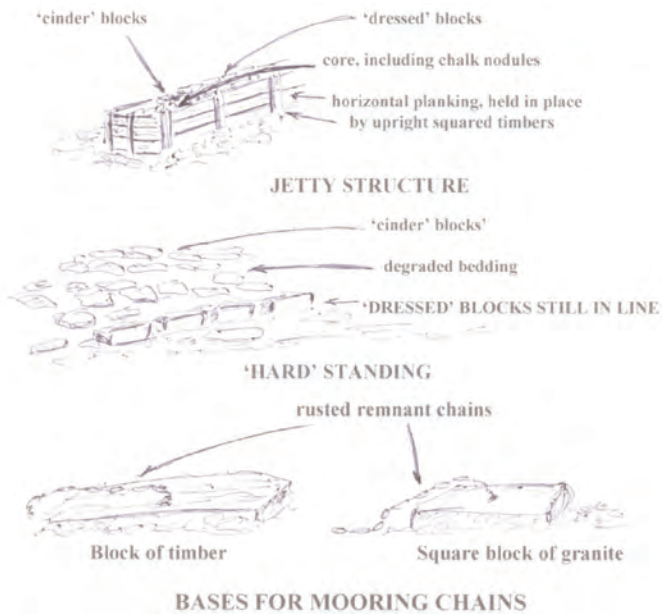

Figure 1. Remains of jetty structures.© J. Edwin Jarvis

The Biological Aspect

Two small 'outcrops' were found along the walk, both showing promising signs of contained fauna. Both were bagged up for later processing and the specimens found are listed in Tables 1 and 2. Specimens found loose on the foreshore are listed in Table 3.

The first sample (Table 1) is from an 'outcrop' of sandy gravel just below the surface of the foreshore at about mid-tide level, map reference: TQ (51) 301805. It contains both freshwater and marine/brackish water specimens. The presence of two molluscs shows this to be a fairly recent deposit. *Potamopyrgus antipodarum* is a native of New Zealand and was first recorded from Britain in about 1850. *Dreissena polymorpha* is a native of the Caspian and Black Seas and was first recorded in Britain about 1820. The presence of fly ash, probably from Battersea Power Station which was operational between 1937 and 1980, provides a more constrained date. There is a lot of imported sand near Festival Pier and this may have contributed to the sample. The sand possibly came from the Thames estuary on the basis of the marine specimens found.

The second sample (Table 2) is from an 'outcrop' of gravelly clay exposed near low-tide mark, map reference: TQ (51) 302805. Nothing shattering was found in this sample. It is a rather nondescript list but lacks the alien species so the sample probably predates their introduction. Table 3 lists specimens found loose on the foreshore and complements the above descriptions. (AD)

Table 1 Specimens from sample of Sandy Gravel, just below surface of foreshore at about mid-tide level: Thames Foreshore on South Bank between Waterloo Bridge and Blackfriars Bridge, Southwark, London S.E.1 Map Reference: TQ (51) 301805. Collected 21st July 2005.

FRESHWATER MOLLUSCS		
Theodoxus fluviatilis (Linnaeus, 1758)	(RIVER NERITE)	a few
*Valvata cristata (*Müller, 1774)	(FLAT VALVE SNAIL)	a few
Valvata piscinalis (Müller, 1774)	(COMMON VALVE SNAIL)	several
Potamopyrgus antipodarum (Gray, 1840)	(JENKINS'S SPIRE SHELL)	dominant
Bithynia tentaculata (Linnaeus, 1758)	(COMMON BITHYNIA)	frequent
Physa sp.	(BLADDER SNAIL)	one
Lymnaea auricularia (Linnaeus, 1758)	(EAR POND SNAIL)	one
Lymnaea peregra (Müller, 1774)	(WANDERING POND SNAIL)	common
Anisus vortex (Linnaeus, 1758)	(WHIRLPOOL RAM'S-HORN)	several fragments
Gyraulus albus (Müller, 1774)	(WHITE RAM'S-HORN)	several
Gyraulus crista (Linnaeus, 1758)	(NAUTILUS RAM'S-HORN)	frequent
Ancylus fluviatilis (Müller, 1774)	(RIVER LIMPET)	common
Acroloxus lacustris (Linnaeus, 1758)	(LAKE LIMPET)	one
Unio pictorum (Linnaeus, 1758)	(PAINTER'S MUSSEL)	two valve fragments
Sphaerium corneum (Linnaeus, 1758)	(HORNY ORB MUSSEL)	frequent
Pisidium amnicum (Müller, 1774)	(GIANT PEA SHELL)	several
Pisidium casertanum (Poli, 1791)		*
Pisidium subtruncatum (Malm, 1855)		
Pisidium supinum (A. Schmidt, 1851)		
Pisidium henslowanum (Sheppard, 1823)		
Pisidium nitidum (Jenyns, 1832)		common
Pisidium moitessierianum (Paladilhe, 1866)		
Dreissena polymorpha (Pallas, 1771)	(ZEBRA MUSSEL)	several
OTHER NON-MARINE GROUPS		
Chara sp.	(STONEWORT)	several gyrogonites
Rubus fruticosus (Linnaeus, 1753) agg.	(BRAMBLE)	endocarps frequent
Other fruits		
Alnus glutinosa (Linnaeus, 1753) Gaertner	(ALDER)	one female strobil axis
Wood fragments		common
Plant root tubes		several
*Eriocheir chinensis (*Milne Edwards)	(CHINESE MITTEN CRAB)	several exoskeleton . fragments
Herpetocypris reptans (Baird, 1835)	(Ostracod)	several
Teleost fish vertebrae and other bones		frequent
Leptocerid?	(caddis fly cases)	several
True fly puparia		two
Cristatella mucedo	(Bryozoan statoblast)	one
MARINE/BRACKISH-WATER SPECIMENS		
Ammonia batava (Hofker, 1951) agg.		
Quinqueloculina seminula (Linnaeus, 1758)		
Triaxon sponge spicules		two
Nucula sp.	(NUT SHELL)	one valve fragment
Ostrea edule (Linnaeus, 1758)	(OYSTER)	several valve frags
Serpulid worm tube fragment		one
Cyprideis torosa (Jones, 1850)		frequent
Balanid barnacle plates		frequent
Stick bryozoan		
Ophiura sp.	(Brittle-star)	a few lateral arm plates
CHALK FOSSILS (LATE CRETACEOUS)		
Cytherella ovata (Roemer, 1840) agg.	(Ostracod)	one
*Bairdoppilata pseudoseptentrionalis (*Mertens, 1956)	(Ostracod)	one
HUMAN CONTAMINATION		
Glass fragments		
Fly ash		
Pieces of coal		
Slag		

* The list of Pisidium species is only provisional, although it should be correct.

Table 2 Specimens from sample of Gravelly Clay, exposed near low-tide mark
Thames Foreshore on South Bank between Waterloo Bridge and Blackfriars Bridge, Southwark, London S.E.1 Map Reference: TQ (51) 302805. Collected 21st July, 2005

FRESHWATER MOLLUSCS		
Theodoxusfluviatilis (Linnaeus, 1758)	(RIVER NERITE)	fairly common
Valvata cristata (Müller. 1774)	(FLAT VALVE SNAIL)	a few
Valvata piscinalis (Müller, 1774)	(COMMON VALVE SNAIL)	common
Bithynia tentaculata (Linnaeus, 1758)	(COMMON BITHYNIA)	abundant,especially isolated opercula
Lymnaea peregra (Müller, 1774)	(WANDERING POND SNAIL)	common
Planorbis planorbis (Linnaeus, 1758)	(RAM'S-HORN)	one
Gyraulus albus (Müller, 1774)	(WHITE RAM'S-HORN)	
Gyraulus crista (Linnaeus, 1758)	(NAUTILUS RAM'S-HORN)	
Ancylus fluviatilis (Müller, 1774)	(RIVER LIMPET)	several
Indeterminate unionid mussel fragments		frequent
Sphaerium corneum (Linnaeus, 1758)	(HORNY ORB MUSSEL)	
Pisidium amnicum (Müller, 1774)	(GIANT PEA SHELL)	* common
Pisidium casertanum (Poli, 1791)		common
*Pisidium subtruncatum (*Maim, 1855)		common
*Pisidium supinum (*A. Schmidt, 1851)		common
Pisidium henslowanum (Sheppard, 1823)		common
Pisidium nitidum (Jenyns, 1832)		abundant
*Pisidium moitessierianum (*Paladilhe, 1866)		common
FRESHWATER BRYOZOAN		
Cristatella mucedo (Cuvier)	(statoblast)	one
*The list of Pisidium species is only provisional but should be broadly correct.		

Table 3 Additional specimens found loose on foreshore
Thames Foreshore on South Bank between Waterloo Bridge and Blackfriars Bridge, Southwark, London S.E.1
Collected 21st July, 2005

MARINE		
Littorina littorea (Linnaeus, 1758)	(EDIBLE WINKLE)	fairly common
Buccinum undatum (Linnaeus, 1758)	(COMMON WHELK)	a few
Mytilus edulis (Linnaeus, 1758)	(EDIBLE MUSSEL)	fairly common
Ostrea edule (Linnaeus, 1758)	(OYSTER)	common
Pecten maximus (Linnaeus, 1758)	(SCALLOP)	several valve fragments
Aequipecten opercularis (Linnaeus, 1758)	(QUEEN SCALLOP)	several fragments
Chlamys varia (Linnaeus, 1758)	(VARIABLE SCALLOP)	a few fragments
Arctica islandica (Linnaeus, 1767)		one hinge fragment
Cerastoderma edule (Linnaeus, 1758)	(EDIBLE COCKLE)	several valves
Macoma balthica (Linnaeus, 1758)	(BALTIC TELLIN)	one valve
Pomatoceras sp.	(Tube worm on beach pebble)	one
NON-MARINE		
Viviparus viviparus (Linnaeus, 1758)	(COMMON RIVER SNAIL)	fairly common
Unio pictorum (Linnaeus, 1758)	(PAINTER'S MUSSEL)	several valve fragments
Sphaerium corneum (Linnaeus, 1758)	(HORNY ORB MUSSEL)	fairly common
Pisidium amnicum (Müller, 1774)	(GIANT PEA SHELL)	several valves
Corophium curvispinum (Sars)		frequent bodies on strand lines
Gammarus pullex (Linnaeus, 1758)	(FRESHWATER SHRIMP)	several live
Eriocheir chinensis (Milne Edwards)	(CHINESE MITTEN CRAB)	ecdysed exoskeleton fragments frequent
MISCELLANEOUS		
Cow lower premolar enamel and horn core		
Sheep lower premolar		
Rabbit pectoral bone		
Pistachio shells.		
Helianthus annua (Linnaeus, 1753)	(SUNFLOWER)	several half achenes
Porosphaera globularis (Phillips)	(FOSSIL SPONGE FROM CHALK)	one
Stigmaria	Carboniferous plant	root cast
Fragmentary clay pipes		fairly common

A visit to the Belgian Ardennes

Gladys Dinnacombe

I had arranged to visit a friend for a long weekend. I was not expecting to be looking at rocks but at ancient sites and the wonderful scenery. But once you have spent time looking at landscape and how it is formed then it becomes a habit to do this each time you visit somewhere new.

The Ardennes region in Belgium consists of three provinces; Namur, Liège and Luxembourg. The Ardennes is also the massif spreading in three other countries, Luxembourg, France and Germany. Its forests date from the Roman period and the name itself, Ardennes, comes from the name of a goddess, Arduina.

The region can be divided into the Lower and Upper Ardennes. The Lower Ardennes is a series of plateaux at an average altitude of 200 - 500m, extending southwards from the river Meuse. It is composed mainly of limestone and schist, although sandstone is found in the wooded areas. The Upper Ardennes consists of plateaux and gently rounded summits rising to more than 500m.

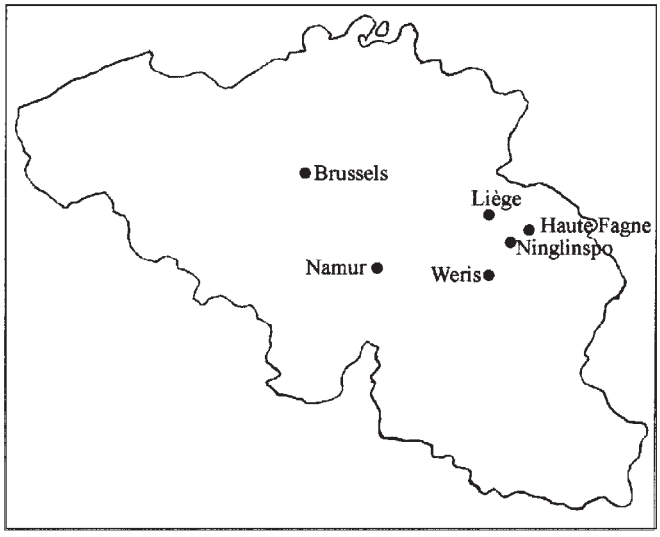

Figure 1. Sketch map of Belgium

The Haute Fagne at 694m is the highest point in Belgium and is mainly peat bog (Figure 1).

The first day was to be an introduction to the area. Ninglinspo was the first place to stop. Located in the area of Aywaille, the Ninglinspo is sometimes called the 'Ruisseau of Hornay'. The Ninglinspo is a tributary of the river Amblève and joins the latter on its right bank near the village of Sedoz. This wooded area is very popular both in winter and summer and there are several walks which traverse the forest. The valley of the Ninglinspo is set in the rocks of the Massif of Stavelot. The bed of the river and its sides are strewn with blocks of quartzite such as those found in the quarry at Funds located not too far away. In summer when the river is full, there is often a surge of water carrying many stones with it. There are many potholes in the bed of the river and these have names such as 'Bath of Diane,' 'Bath of the Otter', etc.

A path wound through the woods by a stream flowing quite swiftly over rocks and boulders. Small bridges criss-crossed at places. The sun shone through the leaves and added magic light to the water and the rocks. It was a wonderful place to be. I felt the stresses and strains of the last few weeks draining away. The sun felt warm on my face and the flowing water was refreshing and restoring. I felt I could sit here for hours breathing in the clean air and listening to the sounds of nature (Figures 2 & 3).

Figure 2. Typical scenery in the valley.

Figure 3. Marteau Formation?

This area is also very interesting geologically. In the Lower Cambrian, the sediments which constituted the future Stavelot Massif, were deposited in a platform/terrace environment. By the Middle and Upper Cambrian, the pressure of deepening turbidites was evident. The Cambrian in the Ardennes is represented by over 2km of 'phyllades', quartzites, and quartz-phyllades lying concordantly without an apparent gap.

The rocks of the Stavelot Massif can be divided into two groups (Figure 4). At the base, the Deville group of quartzites and pale schists/slates emphasises the transition from platform/terrace environment to a deeper basin. Above, the Revin group consists of black shales relatively rich in uranium and pyrrhotite.

At the start of our walk, the shales in the river bank and outcrops in the woods were mainly of the La Gleize Formation which is part of the Revin Group. As we climbed uphill, moving away from the river we came to the Quarreux Conglomerate which rests discordantly on the Revin Group. This conglomerate is Devonian and is overlain by the Marteau Group, also Devonian (Figure 5). This can be seen also down by the river but the outcrops are dif-

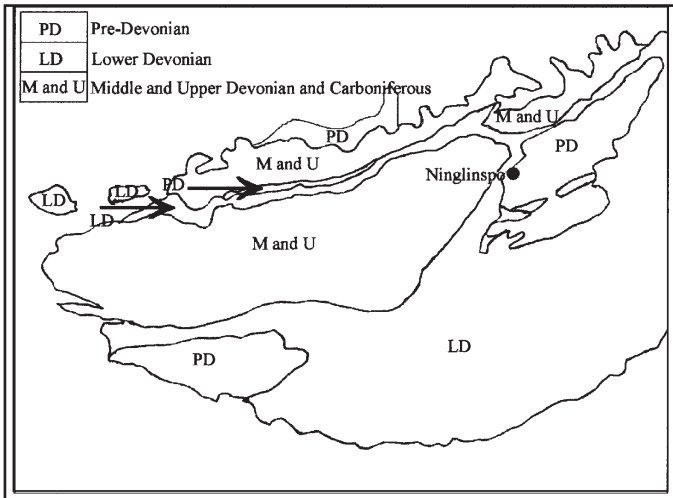

Figure 4.Sketch map of the geology of the Ardennes area (after Sintubin 2004).

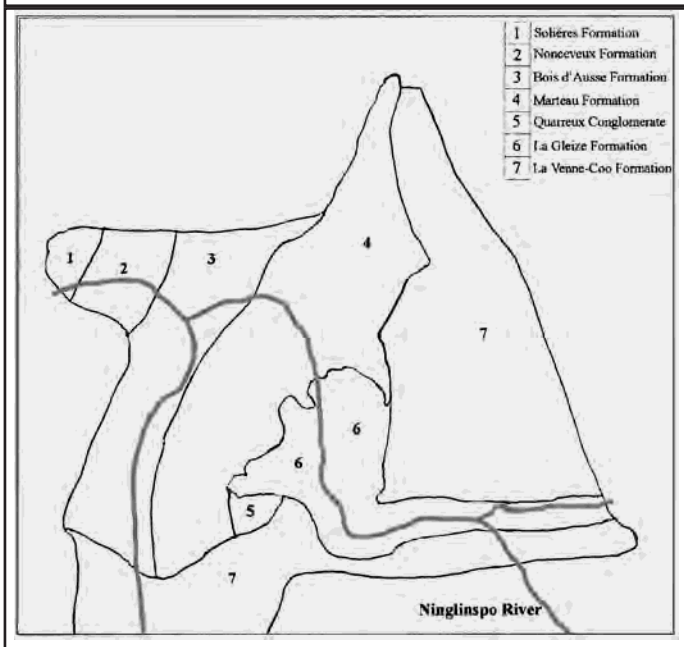

Figure 5. Sketch map of the geology of the area around Ninglinspo (after Sintubin 2004).

ficult to get to and very slippery as they are covered in lichen and moss. Synclinal structures can be seen here too and I hope to return for a longer visit so that I can fully appreciate the geology of this small area.

After lunch at Remouchamps we travelled to Weris. This is the stone age capital of Belgium and a very special place to visit. The first stop was at the dolmen known as Alleé Couverte Nord. It is built using sixteen very large stones and when it was excavated in 1906, three incomplete skeletons were found. All the megaliths in this area date to around 2400 - 1600BC and belong to the Seine-Oise-Marne culture. A walk took us to another dolmen known as Alleé Couverte Sud which uses twenty stones (Figures 6 & 7). Nearby are four standing stones (Figure 8).

The stones themselves are interesting geologically. The dolmens are built in a local conglomerate composed of sandstone, quartzite and flint in a fine, sandstone matrix. Although difficult to work, the stone was quarried commercially from around 1866 to the years of the First World War. The rock was extracted and cut into

Figure 6. Allée Coverte Nord.

Figure 7. Allée Couvert Sud.

Figure 8. Standing stones.

large rectangular or semi-circular blocks and transported by special horse-drawn carriages to the nearby railway station. From there the stone was taken to Liège, where it was mainly used in the construction of blast furnaces. The old quarry is now hidden in the woods.

Returning to the village we refreshed ourselves with cups of tea and looked around the small museum. Artefacts found during excavations of the dolmens can be seen as well as other items of interest. From here we walked along the edge of the hill and climbed to the top to see the stone known as Pierre Haina, or the White Stone, although it is also known as the Stone of the Ancestors. Each year, this stone is painted white but there is a legend associated with it as well. It is believed that there is a tunnel

beneath the stone, which leads to the centre of the Earth. On certain nights, a mysterious being lifts up the stone and flies around the fields. It then descends to a megalithic construction known as the 'Lit du Diable', the Devil's Bed where it rests until dawn. Then it returns to the White Stone and disappears down the tunnel (Figure 9).

Figure 9. Pierre Haina.

The Pierre Haina is aligned with the Alleé Couverte Nord and looking at a map of the area you can see that the megalith positions reflect the constellation of the Great Bear.

After breakfast the following day, we set off towards Liége and the archeosite of Ramioul. But on the way we stopped in the woods near Spa. The autumn colours were starting to show and the trail led down to a bridge over the stream. The stream here also runs through shale. After pausing to enjoy the natural sounds of running water and birdsong, we returned to the car. At the end of the woods, at the road junction was a large building and in its grounds were several springs and shrines. Spa was the world's first health resort, established in the 16th century. Henry VIII was known to visit often. One of the springs is named after Peter the Great. There are a large number of springs, both still and sparkling and they contain iron and bicarbonates which are good for arthritis and rheumatism amongst other things.

After some necessary shopping we travelled on to the archeosite at Ramioul. Not only is this a museum but there are activities to take part in and a cave to descend. But first I will describe the museum. To move through it and to activate some of the audio-visual items, you need to press the hand symbol. After a short introductory film you move through artefacts set in a landscape like the one in which they were found. The story of our ancestors in this area can be followed quite easily and with great interest. At one point, there are three cubicles to enter. One represents the area before the Ice Age, one in the Ice Age and one afterwards. In each cubicle you can enter the landscape and move around it using a joystick. This is a profound experience. I would like to return to this museum again so that I can partake of it once more.

A talk followed, in a building which had been designed to present many other artefacts in a suitable setting. Our group, for we had joined others by now, was entranced by our speaker who demonstrated how some of the artefacts were made and used, and demonstrated how fire was made at those times.

From there we moved to our first hands-on experience. This was making a small clay pot. We were given a small ball of clay which we moulded with our fingers to make a hollow in the centre. We then made patterns using a small thin stick. Our pots hardened by themselves while we moved on to other experiences. The next one was the spear throwing. This was done by using a spear thrower and it seemed quite hard to do. A spear thrower is a stout piece of wood, which fits loosely on the bottom of the spear shaft and acts as a lever. It is put over your shoulder and when brought forward quickly, the spear point flies forward much faster than the usual one-piece spear.

From there we moved to an area which had a large mound of flint. We each chose a piece of flint and took it to another building. Here we were given a small stone hammer made of granite and a piece of leather to protect ourselves. Knapping flint is much harder than expected but eventually we all had a small sharp piece which we could use to trim a piece of shale. The shale being softer was much easier to work. We made a nice shape and cut notches in its sides. Then we wound a piece of straw around it to make a pendant.

Figure 10. Inside the cave at Ramioul

The cave visit was quite difficult as there were many steps to climb but it was spectacular and the stalagamites and stalactites formed many wondrous shapes (Figure 10). One stalagmite has been dated using the Uranium/Thorium method to 261,100 years ago. The modern discoverers of the cave of Ramioul however, were not the first to cross the cave. About 90,000 years earlier, the first explorer was Neanderthal man. Flints of Mousterian culture were left by these first explorers. The flints were found in the deep galleries but most of the archaeological evidence for the stay of Neanderthal man was found around the entrance and the cave terrace. Animal bones were also found here. Later around 30,000 years ago, the first modern human, Cro-Magnon man, stayed

here. They were nomads, hunters and gatherers. Later still, around 2,200 years ago, a group of farmers buried seven children in an opening in the cliff overhanging the cave. They would not have known about the cave as its entrance was hidden by sediments.

The cave itself has three levels which developed simultaneously although in two phases. The first phase, was a phreatic phase when most of the cave was initially completely drowned. At this time, the hollowing out of the cave was caused by acid water. The Namurian schists located at the north of the cave stopped the hollowing-out in that direction so the cave deepened. Near the cave entrance, erosion forms show the direction of the water current. During the second phase, the volume of water decreased and the water ran out forming an underground stream which disappeared near the Namurian schists. This change of water level can be correlated with the variations in the level of the river Meuse.

On my final day we drove towards the Haute Fagne. The Hautes Fagne is a plateau on the north-eastern border of the Ardennes region and is the highest region of the Ardennes. It is of exceptional interest because of the local diversity of biology, biogeography, climatology, geology, geomorphology and history. The University of Liège has built a scientific station there. It is a National Park and covers over 10,378 acres. Signal de Botrange is the highest part at 694m altitude. We walked along one of the raised wooden pathways through a wild windswept boggy heath. It was almost like being on another planet. Access is restricted to protect the environment which is very fragile (Figure 11).

Figure 11. Haute Fagne.

Returning to Liège for a final meal and walk around the town, it was soon time for me to leave. I have many fond memories of this area and look forward to a second visit next year.

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Author

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Book review

Ecological Census Techniques a handbook by William J Sutherland (Editor), second edition, 2006, Cambridge University Press, 432 pp, £29.99 (paperback) ISBN 0-521-60636-5, £65 (hardback) ISBN 0-521-84462-2.

Conservation and the Environment are areas that are currently very much to the forefront. One important area of conservation involves ecological surveys and this book has everything that anyone embarking on work of this type needs to know. This second edition has been updated and new chapters added which enhance the previous content. The chapters are well structured and organised and can be divided into three areas.

Chapters 1-3 provide an excellent introduction to doing research censuses, they cover planning and its importance, then the principles of sampling (both new chapters). Chapter 3 covers general census methods in detail, giving full information of how to facilitate a wide variety of different methods. This is combined with examples of appropriate calculation methods.

Chapters 4 to 10 form the second part of the book, with each chapter covering census methods and ideas for a specific species. Those covered are plants, invertebrates, fish, amphibians, reptiles, birds and mammals. Each chapter commences with an introduction and then covers the types of census and methods appropriate to that species; this adds to and enhances the methods introduced in Chapter 3.

In the final section Chapter 11 emphasises the importance of the environmental context of any census, covering the measurement of variables. It includes what to measure, when and how to do so. The book concludes with an amusing, but very pertinent, chapter listing the "twenty commonest surveying sins", all of which may seem obvious but are essential in order to avoid errors.

The authors of each chapter are experts in the appropriate field covered. The book is well illustrated with good use made of information boxes to demonstrate points discussed within the general text, particularly within parts 1 and 3. There are comprehensive reference lists at the end of each chapter, those within the middle section being particularly useful for further research. The index is comprehensive and easy to use.

This is a book that could be used by any level of student or interested amateur. I feel it is aimed more at specialist students, but it is still accessible to all levels, due to its structure and varied content. Thus it would be equally useful to undergraduates doing minimal census work (as a good basic text) as it would to students specialising in ecological work. I shall certainly be recommending it to my Environment students as well as making use of it myself.

Niki Whitburn. MSc in Science (Open), BA Hons (Open). Senior Lecturer, Education Studies and Geography, Bishop Grosseteste University College Lincoln.

Nisyros: A Greek Volcanic Island

David Rowe

Introduction

Although not as well known as Santorini, which is much larger and undoubtedly spectacular but more complicated, Nisyros is a splendid place for a volcanic geoholiday. It is one of the Aegean islands of the Dodecanese group and is easily reached by boat from Kos to the north or Rhodes to the south, both of which are served by holiday flights from the UK. The island, at 36° 35' N, 27° 10' E, is roughly circular in plan and about 8 km in diameter (Figure 1). Its highest point, at 698 m above sea level, is Profitis Ilias (a common name for high points on Greek islands!) The central feature of the island is the caldera, the rim of which is 4km wide and from 250 to 600m in altitude while its base is at about 100m above sea level; fumaroles are active in the caldera, notably in 'the volcano' (to use the local name) at its bottom. The resident population of Nisyros is less than 1000, mainly concentrated in the north-western port town of Mandraki; there are also small villages at Pali on the north coast and inland at Emborios and Nikia, as well as some scattered settlements elsewhere. Mandraki is good for accommodation out of the main season (I have been twice in September when pre-booking was not necessary) and the modestly priced Hotel Porfyris away from the sea front can be personally recommended. Paths and tracks provide various opportunities for moderately strenuous walking, and judicious off-trail walking is also possible in many places as many of the agricultural terraces are derelict. Public buses run from Mandraki to Emborios and Nikia (free, although gratuities are welcomed by the driver); both villages are good starting points for walks of geological interest back to Mandraki; some of the public buses also descend into the caldera for visits to the 'volcano', as do many tourist buses laid on daily to cater for day-trippers coming to Nisyros from Kos. A free plastic walking map at 1:50 000 scale and 50m contour interval, produced in 1999 by Beate and Jürgen Franke of Stuttgart in Germany from a GPS and compass survey, is very helpful and is available in Mandraki from local hotels and some travel agencies. (Good maps are a luxury in Greece!)

The geology of Nisyros and its regional setting are described briefly by Scarth and Tanguy (2001) in the chapter on Greece in their book on the volcanoes of Europe, and more fully by Vougioukalakis (1998) in an attractive booklet of 80 pages which is well illustrated with maps, sections, reconstructions and photographs including some thin-section photographs; it also has a coloured geological map at about 1:30 000 scale in the back pocket. These sources have been very helpful in compiling these notes.

Volcanic History of Nisyros

Nisyros is a young stratovolcano. The tectonic setting for recent and current volcanism in Greece is a plate collision involving the subduction of a part of the African plate beneath the Aegean micro-plate at a relative velocity of 5-6 cm a^{-1} in the direction N 50° E or roughly NE (Druitt *et al.* 1999). The plate boundary is the Hellenic Trench to the south of the Cretan Arc which runs from the Gulf of Lakonia (between the two south-eastern "fingers" of the Peloponnese of mainland Greece) through the islands of Kithira, Andikithera, Crete, Kassos, Karpathos and Rhodes; this island arc is clearly recognizable on a map of Greece. The

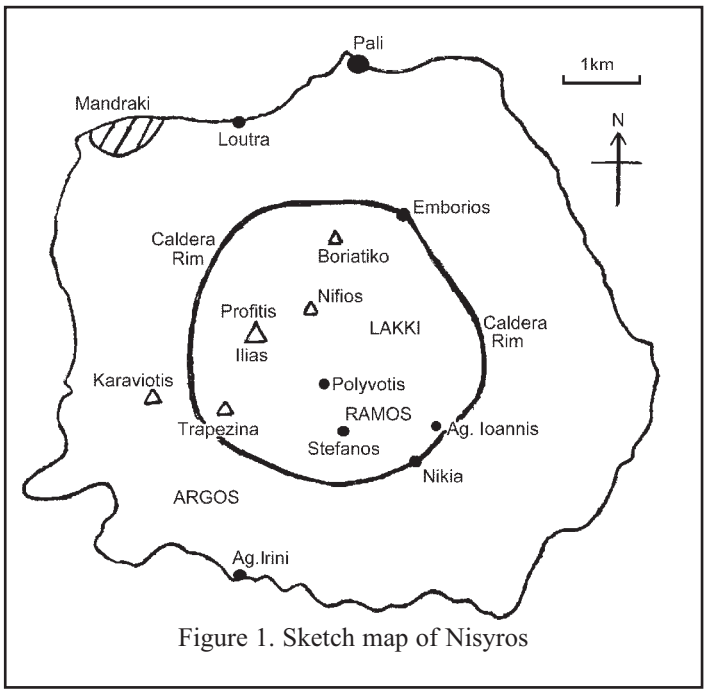

Figure 1. Sketch map of Nisyros

concentric Aegean or Hellenic Volcanic Arc lies to the north of the Cretan Arc and runs from near Korinthos (Corinth) on the Greek mainland through the islands of Egina, Methana and Poros (all three across the Saronic Gulf from Athens), Milos, Thira or Santorini, Nisyros and Giali or Yali, to Kos off the Turkish coast.

Submarine volcanism started in the Aegean Arc about 5 Ma ago in the west and about 2.5Ma ago in its eastern sector. Volcanic deposits accumulated on a 150Ma-old limestone basement (300m deep at Nisyros), and some 160ka ago massive eruptions occurred in the area to the south of Kos although much of the material from them has since been eroded away. But one vent in the Kos complex was the source of material that built up the island of Nisyros which emerged from the sea about 70ka ago; pillow lavas on the shore below the monastery of Panagia Spiliani at the western end of Mandraki remain from that time. By about 50ka BP Nisyros had developed the classical conical shape of a stratovolcano following repeated eruptions which produced a succession of basaltic to andesitic lavas and tephra layers. The final stage of this phase of construction was the massive outpouring of the Argos lava to the south of the island. During the next 25ka the composition of the magma became more acidic (dacitic to rhyolitic) in character and eruptions became more explosive; lavas and associated products of this phase include the Kyra formation (~40 to 30ka BP) to the south and east, and the Emborio lava (~30ka BP) to the north.

After suspension of volcanic activity for a few thousand years, a catastrophic eruption took place some 25ka ago; the centre of the island was blasted out and a vast quantity of tephra was dispersed, resulting in the deposition of the geological formation known as the Lower Pumice which is up to 15m thick in places. Remains of this formation are to be seen, especially in the southern Argos district and in the hinterland behind Mandraki. The explosive eruption also resulted in the formation of a caldera by the collapse of the central zone. Within a fairly short time howev-

er, with relief of pressure in the magma chamber, the fairly quiet eruption of the Nikia lava occurred near the eastern rim of the caldera; a volcanic neck in the cliffs on the inside of the caldera below the rim, north of the Agios Ioannis monastery, today marks the position of the main vent. Thick flows of lava welled up and spilled over the caldera rim and down the eastern slopes of Nisyros; these flows are still prominent in the south-east and are partly traversed by the road between Emborios and Nikia.

About 15ka ago, following a further few thousand years of inactivity, a second catastrophic eruption occurred in the central region and the caldera was re-created with most of the Nikia lava inside the earlier caldera being cleared out at that stage. Ejecta from this episode of volcanism resulted in the deposition of the Upper Pumice which covers much of the northern part of Nisyros today. Some time after the second catastrophic explosion, again following pressure-relief, rhyo-dacitic post-caldera domes and lava flows filled two thirds of the caldera on the western side creating the hills of Boriatiko, Nifios, Profitis Ilias and Trapezina; the dome of Karaviotis, also on the western side but outside the caldera, formed at this stage too. These were the last manifestations of magmatic activity in Nisyros.

However, there have been subsequent hydrothermal or phreatic eruptions extending into historical times. The hydrothermal eruptions resulted from rain and sea water percolating downward in and around Nisyros coming into contact with hot rock and rising hot volcanic gases; the water became converted into superheated high-pressure steam which periodically blew off with explosive violence, ejecting significant amounts of fragmental material in each eruption and leaving a crater; sometimes transient lakes also formed in the process. Such events were presumably more common and much more intense in the aftermath of the magmatic episodes around 15ka ago than today. Rock around the area of the craters became altered by kaolinization. Repeated eruptions, followed by erosion of the soft deposits, would account for the plain mapped as 'hydrothermal explosion products and lacustrine deposits' (Vougioukalakis 1998) now observable over most of the residual caldera floor, especially in its northern sector Lakki. In more recent times the hydrothermal explosions have probably been more subdued. In the southern sector of the caldera bottom (Ramos) there is a group of four named craters of probably fairly recent but uncertain age. The largest of these is Stefanos which is roughly elliptical in plan with long and short axes of about 330 and 260m respectively and an accessible flat (lacustrine?) floor 27m below the main caldera floor. Stefanos, 'the volcano' to the locals and to tourists who visit it in large numbers, "is one of the largest and best preserved hydrothermal craters in the world" (Vougioukalakis 1998). There are fumaroles around the edges of the crater, especially on the eastern side, puffing out sulphurous gases the smell of which pervades the atmosphere: the smell is compounded of hydrogen sulphide and its oxidation product sulphur dioxide with possibly some other acid gases. The interaction of hydrogen sulphide and sulphur dioxide results in the formation of sulphur, and at the edges of several of the fumaroles on the eastern side of Stefanos I saw clusters of very beautiful crystalline needles of sulphur.

About 700m to the north-west of Stefanos, on the lower slopes of the post-caldera dome region, is the Polyvotis group of six named craters; the largest of these is Megalos (= big) Polyvotis, a bit smaller than Stefanos. The craters are deeply pitted into a small dome. Intense hydrothermal activity was reported in the area between 1414 and 1420 by a visiting Florentine monk, Cristoforo Buondelmonti, although there were no eruptions then. There are, however, eye-witness accounts of later eruptions. From the beginning of 1871 fumarolic activity intensified and towards the end of the year a violent earthquake set off hydrothermal eruptions which led to the formation of two small craters – Polyvotis itself inside Megalos Polyvotis, and Alexandros outside about 200m to the south-west. There were further eruptions in both craters in June and September 1873 together with tremors which were felt all over Nisyros, the September earthquake causing damage in Mandraki. In the interim between June and September the craters vented large quantities of sulphurous steam; in the June event there was a copious mudflow from Alexandros which extended southwards for about 500m. The present steep access path from the caldera floor to the crater group ascends this flow. (Care should be exercised if exploring the Polyvotis craters as there may be accumulations of asphyxiating heavier-than-air carbon dioxide in some of the conical depressions). In 1887 there was again earthquake activity and the small crater of Mikros (= small) Polyvotis was formed explosively on the eastern rim of Megalos Polyvotis; this was the last volcanic eruption in Nisyros but in the 20th century there were earthquakes without eruptions in 1953, 1961, 1968-70 and 1995-98 (Vougioukalakis 1998).

As a result of the geothermal heat, steam and hot springs emerge in various parts of the island.

Yali

Yali (= glass) is an island between Nisyros and Kos, about 4 km NNW of Mandraki. It is almost two islands – two low hills connected by an isthmus of beach deposits; each hill is roughly triangular in plan with sides up to 3km long. Remarkably the SW hill consists of thick layers of pumice topped by a local 'pumice rock' (a mixture of pumice and marine shells), while the NE hill "consists wholly of thick lava flows of natural glass (from which the island takes its name), the famous Yali obsidian and perlite" believed to be less than 10ka old. Slabs of the pumice rock "containing beautiful fossils are to be seen in many houses on Nisyros; they are especially numerous in the walls of the castle of the Knights of Rhodes which encircles the Spiliani Monastery" (Quotations from Vougioukalakis 1998).

Perlite is a modified obsidian with 'perlitic' texture – "a texture found in glassy and devitrified igneous rocks, consisting of curved or spherical to sub-spherical cracks. These are produced by contraction during cooling and occasionally are so strongly developed that the rocks break into a series of spherical units" (Whitten & Brooks 1972). Perlitic obsidian is illustrated nicely on P. 228 of my old edition of Hatch, Wells and Wells (1961).

Volcanism and the Nisyrian Economy

Sulphur (Vougioukalakis 1998)

In Buondelmonti's 15th century report of hydrothermal activity he referred to the islanders gathering sulphur in "great quantities" to sell to passing traders, and systematic extraction by mining the altered rock around the craters started in 1879; an enrichment plant was then set up about 2 km away on the south coast at Agia Irini from which the sulphur was exported, mainly to the Middle East. However, the business declined after 1885 and the enrichment plant was eventually destroyed although remains of it are still to be seen. There was a second phase of intense mining activ-

ity in 1944-45 (presumably during the German occupaton) when the product was sent mainly to Samos, Crete and the Peloponnese.

Pumice and Perlite

West of Pali there is a pier from which pumice is, or has been, shipped out from commercial workings in the hills behind but the principal pumice workings are on the island of Yali. Here active extraction of pumice has been taking place on a fairly large scale since 1956 (Vougioukalakis 1998); the municipality of Nisyros has a financial interest in the workings which generate a very high *per capita* income (Dubin 2005). (Consequences of this include the abandonment of much of the agriculture on the island, so that local wine is no longer produced, and the free bus service!) Perlite as well as pumice is extracted in Yali and presumably also contributes to the Nisyrian economy.

Geothermal Heat

Deep boreholes to locate a geothermal reservoir capable of generating electric power have been sunk in Nisyros. Temperatures of over 500 °C were recorded 1700 m below sea level, suggesting the existence of molten rock at depths of between 3 and 5 km (Vougioukalakis 1998). A development project to produce electricity was massively defeated in a local referendum in 1993 and again, more narrowly, in 1997; after these defeats the project was abandoned (Dubin 2005).

Hot springs at the Loutra (= baths) spa on the north coast of Nisyros between Mandraki and Pali have been used therapeutically since 1872; the maximum temperature of the sulphurous saline water is 46°C (Vougioukalakis 1998).

Note on Names

Transliterations of Greek place names are often variable as, for example: Emborio, Emborios or Emporio; Giali, Yali or Yiali; Mandhraki, Mandraki or Mantraki; Pali or Palli. For names in Nisyros I have followed the usage employed on the Franke walking map and the geological map in Vougioukalakis (1998). Also, in accordance with their usage, I have not included diacritical stress marks in names such as Nikiá, using simply Nikia instead. I have used some Anglicized forms (e.g. Athens, Crete, Lakonia and Rhodes) in preference to their Greek equivalents. In general for Greek islands I have used the forms (such as Kithira, Andikithira and Thira) used on a map of Greece supplied by the Greek National Tourist Office but rejected Nissiros for Nisyros and Sandorini for Santorini.

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Book review

Braided Rivers, ed. Gregory H. Sambrook, James L. Best, Charlie S. Bristow, and Geoff E. Petts, 2006, Blackwell, 390 pp, £75 (paperback) ISBN-13:9781405151214, (hardback) ISBN 10:1405151218.

The majesty and fascination of braided rivers first struck me in New Zealand, seeing the great streams that carry away the detritus of the swiftly eroding Southern Alps out from the mountains and across the Canterbury Plains. And two of those, the Waimati and the Waimakariri, are treated at some length in this equally majestic volume. It is Special Publication no. 36 of the International Association of Sedimentologists, and so of course a highly technical work, bringing together for the second conference on braided rivers in 2003 work done in many relevant fields since the first conference in 1992. It is only in this last dozen or more years that research on braided rivers has approached the detailed study that has been done on single channel meandering rivers.

So the study of the dynamics of braided rivers, it seems, has been revolutionized in these past years, and the bulk of the articles are highly technical accounts of various models for understanding the behaviour of these rivers, analyses of bed load and other sediment transport, and morphological analysis and prediction of bifurcations. But there is also a great deal about the human impact on these rivers, focussing particularly on the Tagliamento in north east Italy, the Brahmaputra-Jamuna in Bangladesh, and the Waitaki in New Zealand. These and many other braided rivers have been subject to such operations as channelization, dam construction, and mining for sediment, particularly gravel. “Today, most gravel-bed rivers bear little resemblance to their highly dynamic natural state… However… remaining braided rivers are among the very limited areas, in otherwise highly managed landscapes, where natural large-scale disturbances still are allowed to occur” (p. 339).

For the general reader the ecology of braided rivers, “among the most endangered ecosystems” (ibid.), is probably the most interesting section. This is partly because in their natural state they conform to the “shifting habitat steady-state concept”, and partly because of the effects of human intervention. These effects for instance include on the Waitaki “an invasion of the riverbed by exotic vegetation, notably willow, broom and gorse” (p. 313). In many countries “during recent decades river restoration activities have increased rapidly [but] although a huge amount of detailed environmental knowledge has been compiled, up to 60% of all restoration projects are still ineffective” (p. 354). Braided river management, it seems, is a new art, spanning many scientific disciplines, and clearly still in the infancy of its effectiveness.

Philip Clark, MA (Oxon), BSc Hons (Open)

Scratching the Surface of New Zealand II: The North of South Island

Robin Lewando

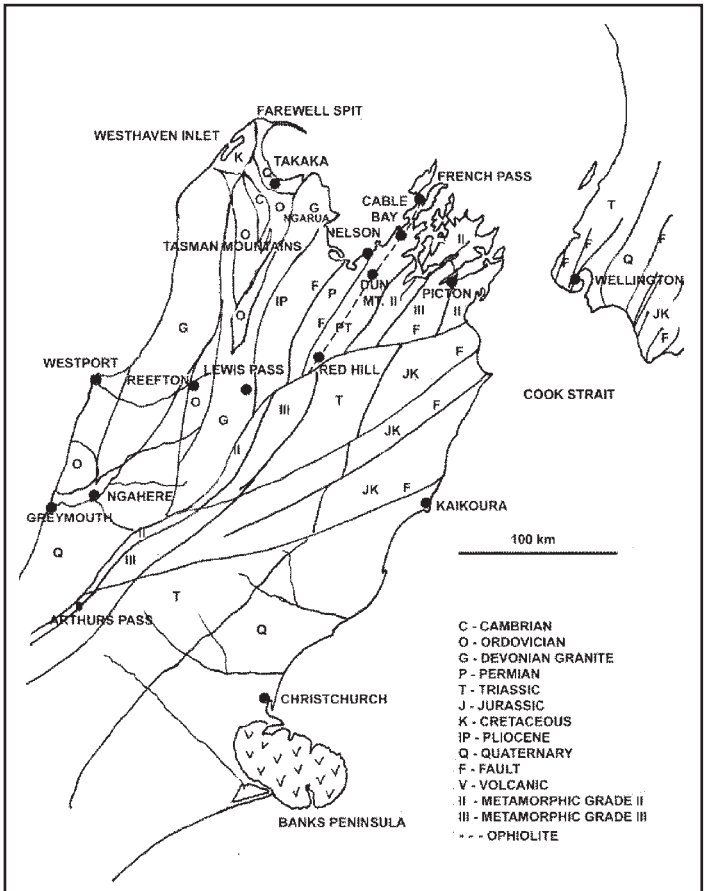

Figure 1. Map showing locations and generalised rock ages mentioned in this account.

After a crossing of about one hour, the Cook Strait ferry nosed its way into Tory Channel at a point on South Island that is actually north of Wellington. The steep rocky slopes on each side give this entrance a fjord-like feel, though the heights each side are not mountainous, and soon become covered in trees and bush. The extreme steepness of these slopes precludes the existence of any roads or tracks. The relief is similar to what we had left in North Island but the rock here is cut by many Tertiary faults, which coastal erosion of the turbulent Tasman Sea has expanded into the fjords, bays and inlets of the Marlborough Sounds. The rocks are well foliated and laminated schist of the older Triassic Torlesse terrane, of a similar age, but less metamorphosed, than back over the Strait. The degree of metamorphism becomes greater to the west. We met the Torlesse rocks later as they form the Southern Alps, though where they are strongly metamorphosed they are named the Haast Schists (Figure 1).

There were houses, with barn and boathouse, situated in some bays, obviously only accessible by water. I am sure I am not alone in dreaming what life in these idyllic and remote places must be like.

Forty minutes of sailing carefully between these beautiful steep and wooded slopes brought us into and through Queen Charlotte Sound leading south-west to Picton. Within ten minutes of docking we were off the boat and into the rain on the South Island of New Zealand

Figure 2. French Pass, with D'Urville island beyond. This is a northern occurrence of the ophiolite amongst the highly faulted Marlborough Sounds. Looking North.

From Picton there was a choice between the scenic but tortuous Queen Charlotte Drive or the highway via Blenheim. No contest! The scenic route from Picton gave a foretaste of what we had yet to encounter in the roads of South Island, and was picturesque despite the rain and low cloud. On the way to Nelson we passed the turnings to French Pass (Figure 2) and also to Cable Bay. French Pass is a minute settlement at the very furthermost tip of the Marlborough Sounds that is reachable by land. The route winds tortuously among inlets and sounds, over ridges and across hillsides that slope down to blue sparkling waters of the Marlborough sounds. Along the way one crosses outcrops of the Croisilles mélange, a very beautiful rock, and the Patuki mélange. These rocks are comprised of fragments of mafic and ultramafic igneous rocks and sedimentary rocks in a serpentinite matrix, and their formation has been linked to the tectonic movements that gave rise to the Dun mountain ophiolite (see below) and the Haast Schists (see above).

Cable Bay in contrast is a sleepy location on the coast north of Nelson, named for this being where the first trans-Tasman Sea telegraph cable came to shore. Prior to that the bay was named Schroeder's Mistake. At Cable Bay a boulder bank, like that found further south enclosing Nelson haven, separates the bay from the inlet behind where the Wakapuaka River reaches the coast. Pepin Island lies between Cable Bay and Delaware Bay and is connected only by the boulder bank. It is here that the Cable Bay Granodiorite can be found, from which the boulders that comprise this bank and that at Nelson Haven come, about which more later.

Arriving in Nelson, we were amused to note that the most striking thing, aside from the terrain, was the large number of Morris 1000's on the road all looking to be in a very good state of repair. It seemed that the Kiwis like their old cars and look after them. The high rate of evaporation here is another factor in their preservation.

Nelson is the geographical centre of New Zealand, from where the first surveys of South Island were based. It is an attractive,

Figure 3. Dun Mountain. The clouds came down, but there in the foreground is a nice lump of Dunite. Looking West, note the lack of plant growth due to toxic minerals.

modern and clean city with tree-lined streets, and was originally settled about 1850 around the Maori settlement of Whakatu, being the second European city to be established in New Zealand. The road plan is very square and modern, with most streets being named after some connection to the British Navy, as the city name would suggest: Achilles Avenue, Ajax Avenue, Collingwood Street, Nile Street, Hardy Street, Trafalgar Square, and St Vincent Street. There is also Rutherford Park, named after the great scientist Ernest Rutherford who was born nearby at Wakefield.

Dun Mountain nearby (Figure 3) is so called because, due to the high level of nickel, chrome and other metals which are poisonous to deep rooting plants, it has only low growing and impoverished plant cover giving the mountain a dun colour from a distance. That is the general story, though as I found when I later climbed to the top, the Dunite up there has a very distinctive Dun or Yellow ochre colour. This is the type area for Dunite, a medium-to coarse-grained ultramafic rock comprising over 90% olivine, of mantle origin, hence the Dun Mountain Ophiolite. The mountain was mined for chrome and copper with oxide and sulphide minerals and even native metal being found here. New Zealand's first railway was the Dun Mountain railway which was used to transport the ores, under the pull of gravity, to the port at the base of the mountain.

The area around Nelson occupies a fascinating geological position on the boundary between the Western Province and the Eastern Province. The Eastern Province, to the east and south, comprises the Torlesse, Caples and Dun Mountain-Maitai terranes, being Permian-Triassic aged sedimentary deposits within which the Dun Mountain ultramafic and Livingstone Volcanics groups occur. The Dun Mountain-Maitai terrane also runs down the curve of the western coast of North Island all the way from Auckland, beneath the post-Cretaceous cover, its presence betrayed by the Stokes Magnetic anomaly. It surfaces in South Island where it outcrops from the Marlborough Sounds down to the Richmond Ranges south of Nelson, at Red Hill by the Alpine Fault. Over to the west from Nelson, towards and in Golden Bay, the Western Province occurs, comprising the much older Cambrian to Ordovician volcanics, schists and sedimentary deposits of the Takaka and Buller terranes. These represent the original basement of the area when it was part of Gondwana before the great continent split up c 85Ma. The Western Province rocks in this area have been displaced over 450km along the Alpine fault complex from matching rocks to the east of the Alpine fault down in the south, the most significant marker being the Dun Mountain ophiolite. The Alpine Fault complex is present some 30 km south of Nelson trending east, and curving away south down the length of South Island.

Nelson is a convenient centre from which to take excursions to check out all this geology. Nelson is also, statistically, the most likely place in New Zealand for earth tremors to occur. The granite and granodiorite of the Median batholith, of which the Cable Bay granodiorite is a northern outcrop, underlies the Pliocene gravels in the land between Nelson and Motueka, an area known as the Moutere Depression. The Median Tectonic Zone and Dun Mountain Ophiolite represent the joining between the Palaeozoic Western Province rocks and the convergent margin represented by the Eastern Province. The rocks of the Median Tectonic Zone are largely subduction-related intrusives, with associated sediments. This Median Tectonic Zone extends across the Cook Strait, at depth, and halfway up the North Island.

This is a good point at which to mention the tectonic history and the formation of New Zealand. Sediments derived from the great southern continent of Gondwana were deposited as both deltaic coastal deposits and deep water marine greywackes off the coast of Gondwana between what was to become Australia and Antarctica, from Cambrian through to Devonian times. These were eventually accreted onto the continental edge, adding to the deposits already there, as the ocean there closed. A second phase of accretion occurred, of principally volcanic and marine sediments associated with the final closure of the Southern ocean which is represented by the ophiolite, up to the start of the Cretaceous period 130Ma. In the late Cretaceous, about 85Ma, this part of Gondwana split away as the Tasman Sea opened up, New Zealand assuming its present position across the sea from Australia some 60Ma. This isolation helps to explain the unique flora and fauna which is often described as 'Jurassic rainforest' in tourist literature. The tuatara populations remaining on offshore islands are held up as survivors of the dinosaur extinction, and New Zealand's native frogs are the most primitive in the world.

Leaving Nelson we headed for Christchurch by way of the Lewis Pass. As we drove along the road following the coast south-west past Tahunanui, Haulashore Island and Fifeshire Rock (named for the ship that grounded on this rock at the original mouth of the haven) we noticed striking differential erosion on the beach, so we stopped and examined the beds more closely. I have subsequently seen a photograph of this beach in a textbook of geology. The beds are of Miocene age, comprising a sequence of sand, mud and siltstones.

We drove through Richmond to Wakefield, through lovely valleys with small groups of farm buildings, long straight roads between hills the tops of which were wooded. The road climbed up into the hills and the trees closed in around, some of them showing bright and beautiful autumn colours. The trees and woodlands in South Island were noticeably different from the bush in the North - generally the trees were a fairly recognisable mix of coniferous and deciduous species. There were also many forestry areas of planted conifers. We turned into Hope Saddle Scenic Reserve which was like a small public park, but it all appeared to be natural and

unmanaged. The area was covered in tea trees (Manuka and Kanuka), Phormium flax, and gorse – which in New Zealand is an introduced pest they are trying hard to eradicate. When pinched, the tea tree emits a very sweet and aromatic scent. This tree, as well as being the source of tea tree oil and soap, also gives the nectar that bees use to make the famous manuka honey. The green leaves were apparently used by early settlers as a tea substitute – hence the name.

There were spectacular views of the mountains of the Northern part of the Southern Alps into which we were driving, and two information boards pointed out and named the peaks and valleys visible in both directions. To the south was the view across the Buller River and into the Nelson Lakes National Park where lakes Rotoroa and Rotoiti lay, with Mount Travers in the Spenser Mountains, and west of that Mount Victoria in the Victoria range; while to the North West lay the Mokihinui forest and Mount Owen.

The air was full of the aromatic scents of manuka, flax, bracken and gorse flowers and the spot was one of beauty, peace and relaxation. But we were only a short distance along the road to Christchurch, so pressed on. Leaving the reserve we turned right onto the main road and headed south for the Lewis pass.

The roads in the South Island are of the same high quality as those in the North, but the curves, bends and rises keep a driver on his toes.

Driving on south we caught sight of an interesting juxtaposition of rock types on the right side of the road, near the junction with Moonlight Road. We stopped, took a sketch, took a photo and took some samples. Taking worthwhile samples in New Zealand often presents problems. Keeping hammering to a minimum and not wanting to damage any exposures one is constrained to searching for large enough pieces of debris that would, when broken open, yield fresh and unweathered surfaces. In almost all cases this proved extremely difficult although there was no shortage of debris and we soon reached the conclusion after examining the in situ rock as well, that weathering proceeds very quickly and very extensively in New Zealand, presumably due to the high moisture and high temperatures. In fact some areas of South Island are being uplifted at as much as 20mm a year but weathering and erosion keep pace with this uplift. Hence the very apparent juvenility of the landscape features and relief.

The exposure was a surface expression of the Glenhope fault where quartz-hornblende diorite of the Jurassic Rotoroa Igneous complex is faulted against the white porphyritic Separation Point granite of Cretaceous age.

The countryside became more mountainous, though not to an extreme, with the road tending to follow valleys. We found the same broad river bed appearing again and again between trees and around bends and the road crossed over a bridge where a sign informed me this was the Owen River (all bridges name what they cross). Quite obviously the river will swell considerably in size during the winter and spring months, but at this time it was shallow, broad and really quite inoffensive. As we followed the river bed, the surroundings became more closed in and forested as we wound deeper into the interior and higher up the hills. As the river was a short walk through the woods, I stopped, clambered through the dense woodland, scrambling over, under and around fallen branches and trees covered with ferns, mosses and lichen until I broke through the line of willows and aspen on the shore of the river. I ambled across the shingle of the river bed amongst which was growing some blue spikes of wild Echium. The pebbles on the river bed were a wide selection of types, obviously representative of what lay upstream: quartz hornblende diorite of the Rotoroa Igneous Complex; greywacke of the Torlesse Group; gneiss; and granite from the Separation Point Suite.

Back at the wheel, we eventually arrived at Murchison. From here the mountains rose in height, the road followed and the clouds descended around the tops. The relief remained relatively gentle and vegetated, for mountains, but was not lacking in grandeur and beauty. I am not sure at what point we drove through the Lewis Pass, I was just aware of a rising of elevation, altitude and relief. The descent to the Pacific side of South Island was accompanied by increased cloud and rain. The Weka pass had the most astonishing limestone formations of Oligocene age.

Figure 4. The Weka Pass with its stunning Oligocene Limestone formations.

From the Weka Pass (Figure 4) the road was long, straight and flat all the way into the suburbs and then centre of Christchurch. The number of old Minis on the road was a significant contrast to all those Moggies we had seen up near Nelson.

Christchurch is a very beautiful and stately city with a definite English feel to it. A lovely autumnal tree-lined path runs alongside the gently flowing river Avon through a peaceful and well kept park. I can honestly say no city centre has ever struck me with such serenity before.

Heading south-east, we went down the Ferry Road and up into the hills behind Sumner. We soon found ourselves up on the edge of the Banks Peninsula, a small range of volcanic hills lying south of Christchurch and affording a wonderful view North across Christchurch and the plain beyond; and another marvellous view out into the South Pacific to the east. While driving up to Mount Pleasant and Sugar Loaf we could see the sandy hook that barred the coastal lagoon at Southshore down below on the coast. At the top we could see over the ridge down into Lyttleton Harbour, the inside of an extinct volcano.

These hills are a surprising and complete contrast to Christchurch spread out across the plain below. They rise steeply up out of the coastal plain, the lower slopes near the city suburbs being popu-

Figure 5. Banks Peninsula. A view of the volcanic layers of the southern side of Banks Peninsula, from the beach at Birdlings Flat.

lated by people who enjoy the peaceful and extensive views out over the ocean. The roads up the hill through these residential districts are very steep and wind their way up, eventually leaving the populated areas and breaking into more rural farmland that is reminiscent of Wales, being relatively treeless, more so the higher one goes, and consisting largely of wide open grassed areas, steep slopes and outcrops of rock. The grass was wiry and tough and there were a few flowers remaining which looked like harebells. Continuing on the road we passed some cable cars and also some outcrops of rock which I had to stop and inspect.

The Banks Peninsula is more than just a large hill (Figure 5). It is actually fairly extensive and forms a thumb-like extension out into the Pacific Ocean at the southern end of the Northern Canterbury Plain within which Christchurch lies. The plain stretches away some 30 miles to the north up the east coast of South Island. Banks Peninsula is about 10 miles across, 15 miles long and was formed by a series of eruptions which overlapped from the Cretaceous period until about 6Ma. The first eruptions were of rhyolite and andesite at the 'root' of the peninsula. Later eruptions built the volcano progressively eastwards with andesitic and rhyolitic flows overlying sandstones. The Lyttelton volcano erupted basaltic lava some 12Ma to a height of 1500m which was later intruded by trachyte dykes. From 9.7Ma eruptions continued to move east with the final largest volcano being Akaroa, a basaltic eruption overlying trachyte – eruptions last occurred back in the Lyttelton area with olivine basalts filling the eroded cone. The area of shallow sea between these volcanoes and the mountains of the mainland gradually filled with sediment washed out of the Southern Alps and caused the volcanoes to be attached to the land as the peninsula they now are. The Rakaia, Selwyn, Waimakariri and Ashley rivers still flow across the plains from the mountains to the ocean. The whole of Banks Peninsula is now an Historic Reserve and information boards can be found there describing what is in view.

On the way up to the summit of Sugar Loaf we passed layers of fine sandy sediment containing boulders and stones which are the weathered remnant of pyroclastic deposits of ash and rock fragments. At one point I spotted a dyke of basalt leading up through a red, oxidised pyroclastic deposit to an overlying basalt lava flow – quite a sight for a roadside exposure. The red colour of this oxidised pyroclastic deposit is like nothing we have in England – it is really more akin to the colour of burnt earth in a garden bonfire and is a widespread occurrence across New Zealand.

There are many magpies in New Zealand which are easily recognisable despite the different shape – they are still pied, being black, short tailed with a white back and white bands on the wings. They are as sprightly as our English magpies, and feed off road kills – possums mostly. Australasian Harriers are also abundant, and these also are to be seen on and around the roads.

I would have liked to spend more time on Banks peninsula but we headed west for Arthur's Pass and soon found signs telling me that both Arthur's Pass and Otika Gorge were open. Coming off the plains on State Highway 73 blue sky was visible beyond the mountains where we were heading, but their tops were in cloud. The road wound up valleys and climbed in a convoluted and gradual way always west until we came to Lake Lyndon. By now we were up above the treeline and out into open mountains. The sun was out and the air was clear, the temperature had risen, and rounding a bend in the road the large blue circle of Lake Lyndon amongst the rocky mountain peaks was a breathtaking sight. We turned into the car park by the road there and drove to the edge of the lakeside beach. Lake Lyndon is a tarn of glacial origin high in the mountains. There was still 60km to go to Arthur's Pass.

As we drove on I saw in the distance vast outcrops of rock that were distinctively limestone – the karst type surface was apparent even from a distance. When we drew near we saw the sign pointing off the road to the Cave Stream Scenic Reserve. This was something I could not miss. We crossed a fence into the area of massive limestone outcrops that had been smoothed into vast curved and rounded, sweeping overhangs and knobs of protruding white and creamy yellow limestone which dwarfed everything around. This was the Weka Pass limestone from the Oligocene, named from the site we had passed on the way over the Alps into Christchurch. We followed the limestone pavement up above the valley onto the lower mountain slopes and then turned back, bearing in mind the vastness of this country and the ease with which I could be sidetracked. It then occurred to me that there must be a river somewhere – there was the valley, and the water rounded rocks, so where was the water? We went looking, up the valley, and after a detour found a tumbling river flowing amongst boulders, brambles and thorn trees, very reminiscent of Yorkshire, but sunnier and hotter. We followed the river until it entered a hillside and disappeared into a large cavern.

We pressed on.

The Arthur's Pass road follows the Waimakariri River valley from the direction of the east coast, after which the Cave Stream Reserve cuts north across the actual Arthur's Pass to meet the westward flowing Taramakau River valley. The road north, once over the pass, is largely downhill and is an impressive bit of engineering, a road well worth seeing, in a very steep sided valley. This part of the road between Arthur's Pass and Hokitika crosses the Kakapo Fault, which is a branch of the Hope Fault extending from the Alpine Fault north-east through Hanmer Springs, from where it goes on to the coast just north of Kaikoura; and the main Alpine Fault, in that order. The Hope Fault is quite active with between 15 and 25mm movement per year, with a typical offset of 2m. The Kakapo Fault ruptured in 1929 with a magnitude 7 quake felt throughout South Island, while a 6.7 magnitude

occurred in the 1994 Arthur's Pass quake on a small neighbouring fault. This quake in 1994 caused some 70 landslides, blocking the state highway for a week.

The Alpine Fault is the major fault running the length of South Island, and beyond, with many tributary faults. The average displacement is about 37mm per year but earthquakes are generally shallow due to the high heat flow arising from the uplift of the Alps. The raised temperatures make the rock less brittle at shallower depths than normal. The implication being that movement continues at depth but with deformation rather than failure. There have been four large (magnitude 8) earthquakes on the Alpine fault in the last 900 years – the next is apparently imminent.

Coming out of the mountains we soon came to the West coast road and found our way to Hokitika. This area was rather disappointing in its flatness and drabness after the impressive high relief we had driven through that day. The road tracked the coastline closely, with extensive areas of woodland and mostly rhododendrons to landward which appeared to extend as far as the hills, the foothills of the Southern Alps. Eventually we found ourselves at Woodstock in the gloomy early evening light. Once out of the mountains it had become cool and we could see the sunlight glowing orange on the flank of Mt. Cook away to the south. We booked into Devaney's in Hokitika right on the edge of the beach. From our room we could hear the breakers crashing onto the beach – the Tasman Sea appears to be a very turbulent body of water.

The Hokitika region is famous as a source of jade, the rights to which have been awarded in total to the Maori, and is carved and polished in the area. This jade is actually a rock formed of felted crystals of nephrite and actinolite. These minerals form through the serpentinisation of the more highly metamorphosed greywackes of the Southern Alps. It is known locally as greenstone or in Maori, pounamu. Other greenstones occur but these are either straight serpentine or green quartz, and in fact are not always green – bowenite, a form of serpentine is a beautiful blue. Nephrite jade is apparently recognisable by its unwillingness to break under a hammer and this was one of the qualities for which the Maori treasured it. Pounamu weathers to give a browny yellow to white colour and varies in purity and colour depending on the relative quantities of actinolite and nephrite within it. The town itself has many shops and workshops where the jade, and also bone and paua (the highly coloured shell of the abalone), is worked and then offered for sale. The quality of the work was high and some of it was very beautiful. The area is also one of gold mines, one of which is still active.

Leaving Hokitika and driving north along the coast towards Greymouth, the area was really uninspiring and I was not surprised to find this is an area of Cretaceous coal measures. Greymouth, situated at the mouth of the Grey River, is itself a pleasant enough town in the centre, but industrial around the edges although fortunately not expansive. Any lack of scenic splendour was, however, made up for by the vast outcropping of Cobden Limestone just north of the town, named from the town on the north side of the mouth of the Grey River. Like the Weka Pass, this is Oligocene limestone, which was deposited between 34 and 24Ma. From the Cobden limestone we drove north on the road to Reefton and then took the State Highway 7 to Ahaura.

A sign on the road at Ngahere directed us down to the Grey River where we found the last bucket ladder dredge in the Southern

Figure 6. The Grey River Gold Dredge at Ngahere, a bucket river dredge.

Hemisphere (Figure 6). Having paid a small fee at the office we were directed to drive on down the track to the dredge. Being the only people there we could ramble over this construction at our leisure. It was an awesome sight at 170m long, built up on a pontoon that is itself 80 by 36m. The dredge weighs 3500 tonnes and the bucket ladder consists of 104 buckets that can each hold a tonne of gravel, and which can dig down 30m below water level. The processing inside is a series of trommels or sieves which discard the larger particles, allowing the separation of the gold bearing black sand by gravity. Originally built in 1938 and winning 175,000 ounces of gold up until 1953 in the Hokitika area, and 20,200 ounces in the Kumara area between 1957 and the early 80s, the dredge was dismantled, eventually bought by the present owner and rebuilt from scratch. On the Grey River since 1992, she has processed 90 million tons of gravel, rendering poor quality land in the river channel into good quality grazing. This was a quite incredible piece of machinery. The source of the gold is the alluvial gravels in the bed of the Grey River.

Further up the road to Reefton and on the east side is the settlement and creek of Nelson Creek (Figure 7). This is named for a gold surveyor, who having found gold back in the late 19th century faced a lynching when subsequent mining failed to find any. He persuaded the miners to persevere and this became one of the richest claims in South Island. I tried my hand at panning in the creek but have nothing but black iron sand to show for it. It is a cold and back-breaking task.

Reefton used to be hailed as the site of the oldest rocks in New Zealand, Precambrian, but the discovery fairly recently of a graptolite fossil has reassigned these rocks to the Ordovician. It is, at first sight, a one-eyed little place with little to commend it, but it is worth looking around. It is in the centre of what has at various times been the source area of much gold and also a very profitable coalfield. The latter gave rise to the electricity generating station that made Reefton the first town in the Southern Hemisphere to have electric street lighting. The museum at Blacks Point holds a quite incredible and vast collection of items from the late 19th and early 20th century, the heyday of mining operations, including several extensive collections of rocks and minerals. Best of all was the stamping battery in the shed at the back. This is water powered and has five iron stampers, used for crushing mined

Figure 7. Gold Stamper, at Reefton, powered by water.

quartz from the reefs (whence the name Reefton) which was then washed on to a screen where mercury and cyanide was used to extract the gold. The battery still works – the curator ran it – but no chemicals are used nor gold extracted anymore. And the same water power was also used to power four light bulbs, all large glass globes of 1920s vintage and still glowing.

From there we travelled northward out of the Southern Alps back to Murchison, through to Motueka. The road from Murchison up to Motueka is within the Moutere Depression, an area of low-lying land based on Pliocene quartzo-feldspathic gravels which overlies the Rotoroa complex of biotite granite and granodiorite of late Jurassic age. The depression is fault bounded – a half graben – to the east by the Waimea Flaxmore fault zone which is an area of great activity (Figure 8), making Nelson the city most prone to experience earthquakes in New Zealand. That the Moutere gravels are fertile and flat became more obvious as we ltraveled north closer to Motueka and the coast, with more fruit, hop and vine growing becoming apparent. We pressed on through Motueka on State Highway (SH) 60 turning west and climbing the Silurian and Ordovician hills of Arthur Marble formation. This high ground is headed to the north by Cretaceous granite of the Separation Point Suite that has been placed there by movement on the Wainui shear zone slicing north-west across the top of the marble hills. However, these marble hills contain some incredible caves as I shall mention later.

The road up Takaka hill starts from Riwaka, where a side road leads, eventually, to a point close under the looming height of the hill. And here, the Riwaka River issues out from under the hill, into which it has disappeared some 700m above and 3km away. It flows out in a basin of fern- and moss-covered trees and rocks. Inside the cave is accessible, but two sumps need to be negotiated first, one 12m long – so wet suits only, and a guide is essential.

Takaka Hill road is a series of switchbacks, the summit being eventually reached with the Tasman Sea gleaming bright blue away to the North on the right beyond the hills, next to the site of the Ngarua caves. To the north is the Pikikiruna Range and to the south the Arthur range – Mount Arthur where some scenes for Lord of the Rings was filmed – both formed of Arthur or Takaka marble with an incredible karst landscape. Then within a couple of miles we were negotiating an equally serious series of switch-

Figure 8. Richmond Hills. Ideal at 650m for paragliding. The view is west over the Waimea-Flaxmore fault to Nelson and the Moutere depression, and to the Abel Tasman Park on the other side of the bay.

backs all the way down into the valley. The view coming down was an incredible vista across the farmland of Golden Bay to the trackless Tasman Mountains beyond.

Golden Bay lies facing north between the Tasman Mountains and the sea, a narrow strip of farmland that follows the coast and also penetrates the mountains up some of the river valleys. The Takaka, Aorere, Anatoki, Waikoropupu, Parawhakaoho, Parapara and Onahau rivers.

Takaka is 55km from Motueka and SH60 is the only way to get there. So it can be understood the feeling of seclusion one experiences on descending to the valley amid the green fertile fields, vineyards and orchards. Beyond Takaka lies Onekaka, once a site of an iron ore mine which later became a paintworks that used the iron ore as colourant. The mine owner's front door was apparently painted in every shade of red to yellow imaginable. Onekaka Wharf, down on the beach by the mouth of the Otere River is now just a line of piles marking where iron ore was shipped out.

We stayed at Shambhala, a hostel of great peace and beauty where the beach to the east of Onekaka Wharf was littered with stones of all sort of shapes and colours, with shells equally varied and piles of seaweed. Pebbles of chlorite schist gleamed bright green, and some milkstone which gleamed a pure white in the clear waters of the bay. My pockets were soon bulging. There were also little green sea urchins, sharks' vertebrae and sand dollars.

In the evening the air was warm and balmy and filled with the scents of the ocean, the fields and above all the aromatic plants along the way – tea trees, pine and spruce, gorse and bracken, grass and moss. It was a dream, completed by the stars winking in the sky as it darkened.

The nearby Mussel Inn was an experience I would recommend to everyone, particularly the stumble, in the dark when returning, through glowworm city, a path that is flanked by a damp and mossy bank within which at night glow and wink a thousand glow worms - a disorientating experience that leaves you wondering whether you are facing a city, or a starry sky.

Travelling on, to the western end of Golden Bay, the road to Farewell Spit goes through the village of Collingwood originally

planned by the British as the site of the capital. Plans drawn up in England were found to be useless when they came to the building stage since the original surveyors had omitted the contours of the land and the relief prohibited the situation of most of the buildings.

Puponga at the base of Farewell Spit is a site of a now abandoned coal mining industry from the early 20th century that exploited the Tertiary coal, shipping it out by steam from a wharf built into the bay.

Farewell Spit is a long spit of principally wind blown sand stretching 12 miles out across the larger part of Golden Bay, making the whole bay into a pretty well protected lagoon. The spit itself is not available for public access, except by guided tour, being a bird sanctuary, but the area at the base of the spit and generally around Cape Farewell is a fairly essential point to see.

Beyond Farewell Spit and away to the south, following the west coast is the large inlet of Westhaven. The road, unmetalled, follows the shore line, occasionally cutting across spurs or diving across small gaps of water on a causeway or bridge. Before the road was built travel was across the mud flats at low tide – the way was marked by sticks in the mud, to try to prevent travellers disappearing into the mud. The drive is stunning, and having reached the southern end of Westhaven Inlet, the enormous bluffs of Oligocene limestone that rear up and separate the coast from the interior are seen towering above Mangerakau, once the site of sawmills and flax production, but now a sleepy and isolated scattered community, plagued by mosquitoes at the wrong time of year. The limestone bluffs have some incredible caverns through them, from the west end of which one gets a view out over the Tasman Ocean, and from the eastern end a view out over the Tasman Mountains.

Between Onekaka and Takaka is the Ward-Holmes Road, the route to the famous Copperstain Creek - a source of copper ores, but despite repeated prospecting not in exploitable concentrations - and Parapara Peak. The Peak of Parapara Mountain has an incongruous outcrop of Permian conglomerate, evidence for submergence of land that was subsequently uplifted, eroded, and submerged again in the Tertiary when the vast areas of Oligocene limestone across the north-western part of South Island were deposited.

Figure 9. Cobb Reservoir. This is the view from the ridge before descending. Below is the Cobb Igneous Complex, including large areas of serpentine. Away at the other end are the Cambrian rocks including Trilobite Limestone.

The central core of the Tasman Mountains is Cambrian to Ordovician rocks of the Takaka Terrane, giving way to the west to Ordovician rocks of the Buller terrane and over by the west coast to the Devonian granite of the Karamea suite.

The Cobb Valley is the most accessible point at which to access the Takaka terrane rocks, the oldest in New Zealand, and a popular place for finding trilobite and graptolite fossils. The road there is winding and tortuous and yet again one couldn't help wondering what would happen if the car failed. It didn't. The road passes a trail to an old asbestos mine, about an hour's walk through the bush but well worth it. The mine closed 40 or 50 years ago, but rock and mineral collectors as well as sightseers go there still.

The Cobb Valley has been dammed as part of the Cobb Hydroelectric scheme (Figure 9) and the resulting lake sits in a basin amongst the mountains, some 7 to 8km long, at the head of which is Trilobite Rock, an upstanding limestone olistolith of Cambrian age set within Cambrian siltstones and full of the remains of trilobite carapaces. By the lakeshore nearby is an outcrop of the Balloon formation, a Cambrian diamictite. An excellent booklet published by the Geological Society of New Zealand describes the area and walks in the mountains roundabout in some detail.

On the summit of Takaka Hill there is a turn off to the left and a Lookout point where one can take in the breathtaking view across the Bay to Nelson and the Richmond Range beyond. On a clear, hot and sunny day it is quiet and still up there, with the occasional fantail twittering and fluttering in the manuka trees nearby. The whole area across the top of this part of the hill is the most amazing karst landscape, almost impossible to cross even on foot except by made tracks, being covered by heavily weathered limestone and marble which pokes up through the low growth as peaks and points, separated by deep crevices and grikes. The entrance to the caves is up a set of steps up through some trees, down into a hollow and through a door in the hillside.

The Ngarua caves are formed within the Arthur Marble, named from Mount Arthur further south, although familiarly known as Takaka Marble and which has been used to face the Beehive, the parliament building in Wellington. The Arthur Marble is a metamorphosed limestone of Upper Ordovician age. Rainwater percolating through the soil performed its usual duty of dissolving the limestone and expanding joints and cracks into holes, pots, caves and caverns. The caves here are not very extensive and are an easy walk, but it has not always been the case. Successive owners have explored them and dug out the thousands of years of accumulated silt and deposits that covered the original rock-cut hollows until the current state of the caves was achieved by the current owner, with relatively safe and level walks, railings across the more exposed pit edges and board walks over the sensitive areas. The main cavern, called the Cathedral, is impressively lit to show the extraordinary and beautiful flowstone formations in their full glory. The most significant thing about the Ngarua caves is the bones that have been found there. Principally these are of giant moas, those large flightless birds which populated the land after the last ice age and which are thought to have finally faced extinction with the coming of the Maori – but it seems they were in serious decline anyway. They were larger than anything we know of today, standing some 12 feet tall, like a vast and bulky ostrich. They had a serious predator too, amazingly, the giant eagle, and a

Figure 10. Rawhiti Cave, the largest cave entrance in the southern hemisphere, located in the Pikikiruna Mountains on the east side of Golden Bay.

display in Te Papa museum in Wellington graphically shows the two creatures in conflict. The bones found in Ngarua caves are on display there too, along with bones of other extinct forms of both Moa and Kiwi also found in the caves. The whole tour of the caves is fascinating and although relatively short, in distance and time, very informative – and promises to become more so as some of the side chambers that are still being explored and dug are revealed to the public.

Nearby and 11kms up the gravel Canaan Road is Harwoods Hole, a massive pot hole that drops a stunning vertical 275m to a cave that has its outlet on the Takaka side as the Starlight Cave. It is apparently a heart-stopping abseil down into the entrance. Also in Golden Bay but slightly nearer the coast is Manson, or Rawhiti Cave with the largest cave entrance in New Zealand (Figure 10). Superlative descriptions like this should not be taken lightly in New Zealand – even the norm is impressive, and if a feature has a superlative you can be sure it has earned it. In this case the cave entrance was indeed magnificent, despite being partially infilled by rockfall. The roof of the entrance was covered by dirty brown stalactites, all, interestingly, pointing outwards. It was like the gaping maw of some gigantic monster. We explored inside, but it is not an extensive cave.

The Arthur Marble formation is honeycombed by caves and is still being explored by local and visiting caving groups. One of the systems on Mount Arthur is actually the most extensive system in New Zealand at over 40 km's in length providing a full 3 to 4 day trip to reach the end and return.

It is now two years or more since I made this trip, and I and my partner subsequently stayed in Golden Bay, two months on the west coast on a sheep and beef station amongst the Oligocene limestones and six months on a dairy farm on the aggradation terraces above Takaka, and also spent much time exploring the district. We also toured the rest of South Island in a 1956 Bedford Bus, true to New Zealand form. Having had the opportunity to explore some of the sites and features mentioned, and grasp a better understanding of the country as a whole, I intend following this account up with some more specific and detailed accounts. Hopefully these, besides being of interest, will encourage other geologists to come and visit this fascinating and beautiful country. Believe me, you will not be disappointed.

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Author

Robin has returned from New Zealand after 18 months and has resumed his studies with the OU. Currently living on Exmoor and spending his spare time trying to trace the Roadwater Limestone, which is proving as elusive as the Exmoor Beast.

Book review

Agates: Treasures of the Earth by Roger Pabian with Brian Jackson, Peter Tandy & John Cromartie, 2006, Natural History Museum. 184 pages, 132 of which include full-colour specimen images, £16.99 (hardback) ISBN 0565091956.

Though modestly sized, this is a visually stunning book packed full of high-quality colour images of agates from all around the world; it also includes ten maps showing source deposits and a two-page section illustrating, with comprehensively labelled diagrams, how an agate forms.

Agate is, of course, formed from fluid silicon dioxide seeping through rocks and leaching out minerals until it cools enough to precipitate over time within cavities: this microcrystalline water-rich structure eventually forms a complex chalcedony from which the expert can read the depositional history of the agate.

The book also examines the way agates have been polished, worked for over 7000 years of human history, their use for decorative objects and their fluctuating popularity. There is also a fascinating section on agate terminology, which gives a flavour of the business.

Well-banded agates; agatised coral; agatised wood, brecciated or ruin agate; calico agate; dendritic agate; eye agate; faulted agate; flame agate; fortification agate; jasp agate; lace agate; mocha agate; moss agate; plume agate; sagenitic agate; stalactitic agate; tube agate; level-banded agates; landscape or scenic onyx; onyx; plynthoid onyx; sand onyx; thunder eggs; wave onyx. Other types of chalcedony: bloodstone; carnelian; chert; chrysoprase; flint; jasper; plasma; prase; sard.

Apparently every deposit is unique and it seems there are people whose aim in life is to own one of each type: for them this will prove to be a mouth-watering book. Earth scientists may find much more detail than they think they need, but it will prove a useful compact and affordable reference work. And there's no denying that it has beautiful illustrations.

Sybil Richardson (BA (Hons) Open
and continuing OU student

São Miguel on a Shoestring

Linda Fowler (ed)

Each day written up by a separate group as shown, with figures by section authors unless indicated otherwise.

We do not propose to describe the general geology in detail in this article since there is an excellent overview of São Miguel Island, Azores, in Scarth & Tanguy's *Volcanoes of Europe* which you can use for background reading and selected bibliography from our trip is given at the end. The main purpose here is to describe what we Shoestringers did, during our week on the island, in a way that will enable others to follow in our footsteps.

São Miguel is in the easternmost of the three groups of islands that make up the Azores archipelago and which, like the central group, lies on and around the Terceira Rift, the very slowly separating junction between the African and Eurasian plates and north of the Azores Fracture Zone. São Miguel itself lies partly on and partly to the north of the Rift. The tectonic setting is complex because of the interactions between the Azores hotspot and the spreading ridge.

Because of the complex geostructural setting earthquakes and volcanic eruptions, together with landslides, are common in the area making the study of volcanic related hazards of great practical importance to the islanders. We were particularly fortunate that a contact in the University of the Azores' Risk Evaluation Department, Adriano Pimentel, was able to help plan our programme, accompany us on one of our excursions, and also arrange a visit around the laboratories where he and his colleagues work.

São Miguel Island is formed by a chain of volcanoes and volcanic regions, from west to east these are:

Sete Cidades: an active stratocone with a caldera and later flank and intra-caldera eruptions, around 290ka old with an approximately 5km diameter, 500m deep circular summit caldera, inside which are pumice cones, maars and domes. On the flanks are scoria cones and domes. The Mosteiros graben, a NW-SE tectonic structure on the flank may be a sub-aerial segment of the so-called Terceira rift. The graben crosses the caldera and controls the location of several scoria cones. There is a group of Pleistocene trachytic lava domes, lava flows and pyroclastic flow deposits on the west and north flanks and also submarine vents to the west. The E-W alignment of domes on the west side of the volcano is the surface expression of a deep oceanic fracture. Intersection of NW-SE and E-W fracture trends probably determined the location of Sete Cidades.

The Picos Region: a low lying area of cinder cones where basaltic activity has been concentrated over the last 5000 years; lines of cones and pits mark fissure eruptions concentrated along several approximately NW-SE alignments.

Fogo (Agua de Pau): another active stratocone with a complex summit area that has been affected by erosion, normal faulting and a caldera/crater collapse structure. The Ribeira Grande geothermal field lies on the northern flank and there are also scoria cones, domes and maars.

Furnas: yet another active stratocone which appeared above sea level >100ka ago. The central caldera collapsed about 12ka with an inner caldera formed about 11ka which hosts a particularly active geothermal field. Later eruptions on a ring fracture formed a crescent of tuff rings, such as Pico do Gaspar, and later trachyte domes. The most recent Furnas eruption was in 1630 and the average interval over the last 2900 years has been 362 years. Furnas was one of half-a-dozen "Decade volcanoes" selected by the International Association of Volcanology and Chemistry of the Earth's interior (IAVCEI) as a research focus during the 1990s International Decade for Natural Disaster Reduction (IDNDR). The volcano is potentially explosive and lies in a rural, livestock farming area with an aging population of about 23 000. Research has focused on 1) medical risks and the built environment and 2) linking hazard mapping to evacuation planning.

Povoação: a probably extinct stratocone with caldera which built up on the southern edge of the Nordeste upland area. Lavas were initially basalts, then hawaiites and mugearites, ending with trachytes. Caldera formation was accompanied by plinian explosions of trachytic pumice, perhaps in two stages at 820ka BP and 700ka BP. There is no southern wall: it may have been downthrown along a coastal fault or alternatively swept away by a landslide. There have been no eruptions in this area in the past few thousand years.

Nordeste: The oldest rocks exposed on Saõ Miguel: 4.00 – 0.95Ma old. Thick piles of basaltic flows are probably eroded remnants of an extinct shield volcano

The island thus demonstrates the expected progression through a shield stage (Nordeste), then a post-erosional stage producing stratocones, followed by recent activity around the margins of these.

Since 2005 the Azores have become more accessible with the advent of a weekly direct flight from Gatwick during the summer. This, together with reasonably priced, pleasant accommodation at the Casa do Jardim in Ponta Delgada and the usual group of willing volunteer drivers brought the trip within organiser Jan Ashton-Jones' stringent "Volcanoes on a Shoestring" budget!

We flew direct from London Gatwick to Ponta Delgada on Tuesday 6th June 2006 and spent a week on the island. In the following account distances are given from central Ponta Delgada and where possible UTM grid references are provided.

Day 1 – Sete Cidades

by Heidi Barnes, Steve Bateman, Mike Burrows.

Head NW out of Ponta Delgada, towards the road which climbs up the SE spur of Sete Cidades caldera rim. Pull off the road on left side at about 16.0km, $^{6}11^{164}\,^{41}86^{097}$, by a flat, quarried area in the side of a scoria cone.

Stop 1: Cone on southern side of Pico do Carvão

A basaltic scoria cone, 30m high, quarried for roadstone etc. with other scoria cones nearby in approximate alignment along the NE-SE ridge. Best scoria cone of day, one of the best on the trip. Mostly dark grey, vesicular, twisted/contorted airfall clinker 0.5 – 7cm. No phenocrysts. Baby bomblets (achneliths) occasionally present, up to 10cm.

Areas of red closer to centre of the cone, due to oxidation by passage of volcanic gases through scoria adjacent to the vent. Black scoria – less contorted - on the left below dipping layers. Very fresh surfaces, unweathered, showed bluish iridescence. Colour variations appeared to be caused by changes in oxidation state rather than weathering or lithological variations.

Cross-section showed 10-40cm thick layers on left side of cone dipping to right, overlain with dipping to left away from centre of cone. Layers picked out by grain size variations – coarser standing proud. Linda suggested the basal layers were erupted earlier from the scoria cone to the left.

Continue up the road, stopping to view an old stone aqueduct on the right-hand side.

Stop 2: The old stone aqueduct

Continue up the road, at 19.2km ($^{6}10^{679}$ $^{41}86^{789}$) turn right through gates down a forestry track to $^{69}163$ $^{41}87^{760}$.

Stop 3: Lagoa do Canário

Path down to Lagoa do Canário: the lake itself was mossy, scummy, plenty of frogs, but no exposed rocks (Figure 1).

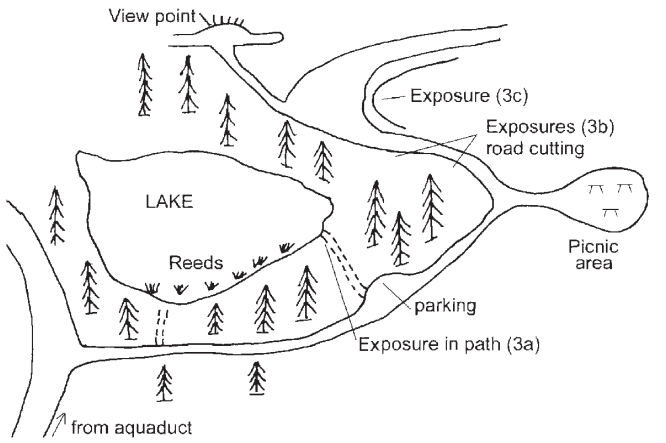

Figure 1. Sketch map showing location of Stops 3a, 3b and 3c at Lagoa do Canário

We drove along the track looking for the exposure shown in our handout, stopping at 3a and 3b to view deposits exposed in the steps to the lake (Sete I, J and K) and deposits exposed in road cuttings.

Drive along track to 20.2km, miradouro turnoff $^{68}997$ $^{41}88^{580}$

Stop 3c: Sete E-L deposits showing erosional unconformity

Down Miradouro road about 500m to $^{6}8^{160}$ $^{41}82^{554}$ on inner curve of right hand bend (Figure 2) we at last found what Linda was looking for: an exposure up to 5m high described in Booth *et al.* (1978).

Below the angular unconformity, up to 0.75m, the layers were horizontal, 5-10cm thick (Sete E/F, I) The grain size was unclear due to lush growth of mosses, rare subrounded clasts up to 8cm protruded from the vegetation. There was no basal lithic bed or palaeosol present. Above the unconformity there were ungraded unsorted clastic layers of angular to subrounded pale vesicular pumice 0.5 - 5cm in pale ash which thinned over topographic highs, the thickest layer overlying the unconformity up to 1.2m thick.

Figure 2. General picture of Stop 3c: exposed face of cutting is about 5m high and shows flow and fall deposits draping an erosion surface.

The next layer was 15-50cm thick, also thinned over the high but not as much, was pale and contained angular fragments but showed slight layering. The next layer was ashy.

Fine layers were picked out in moss. These tended to be more even in thickness up to 15cm thick & draped the hollow-filling coarser layers.

Linda suggested that each pyroclastic density current had finer material that billowed sideways and upwards as a co-ignimbrite cloud; this then settled on top of the ground-hugging flow that filled in gullies with unsorted deposits. Possibly the gullies had been eroded by the pyroclastic density flow itself which had ripped away any palaeosol, alternatively there was insufficient time for a palaeosol to form.

Return to the main road and continue towards Vista do Rei stopping to look at road cuts on the way (23km).

Stop 4a: Road cuts towards Vista do Rei 23km. Good layering in road cuts towards Vista do Rei, some places the layers were horizontal, some sloping up to 20 degrees, of even thickness, draping surfaces, probably airfall, pale pumice.

Continue to the road junction (snack bar) at Vista do Rei (24.9 km) where there is a view into the caldera and south-west to the coast.

Stop 4b: **Vista do Rei**

Linda explained there were three eruption stages, the caldera-forming eruption emptying the magma chamber with ring fractures developing which allowed magma to erupt on the fault lines forming tuff cones. Dense dark semi-rounded pieces of olivine basalt, up to 0.5cm phenocrysts, with rare small coarse-grained white fragments of ?syenite = intrusive equivalent of trachyte .

Turn round and take the left hand fork around Lagoa do Santiago towards Sete Cidades village.

Lagoa de Santiago: no stops, pointing out of windows into Sete Cidades caldera. Dyke in right side of road cut near the caldera centre. More road cuts showing horizontal & sloping layering in pale pumice. Crossing the bridge between Lagoa Azul & Lagoa Verde both looked grey without sunshine. In Sete Cidades village there are restaurants to left past avenue of trees & bus stand, small bar on right with toilets.

Continue through Sete Cidades village towards the western rim of the caldera. Look out for an exposure on the right hand side at 35 km where the road curves round Caldera do Alferes, a small tuff cone to its north.

Stop 5: Caldera do Alferes
Intracaldera tuff cone along ring fracture on western side of Sete Cidades where the road cuts through dune-like shape approx 3m high.

Very weathered and soggy accretionary lapilli, 3mm across: muddy balls formed from wet ash in steam clouds. Fine-grained very light, very inflated subrounded white pumice up to 1cm, ill defined normal grading mostly sub-millimetre sized grains. A few black shiny obsidian clasts 0.5-1.5cm, welded tuff angular fragments with crystalline pyroxene and feldspar pre-existing lithics caught up in the eruption.

Continue up the road, climbing to the gap in the caldera rim and pull into a parking area on the left at 36.2km

Stop 6: North-west rim of caldera
20-25m road cut through tuff cone on, with Pico do Mafra to the right and Mosteiros lava delta straight ahead. On left brown layering up to a metre thick of ash and lapilli, dipping 10° outward from caldera centre. On the right of the road, layers were paler, possibly more rapid weathering shows 'horizontal hoodoos', ventifacts created by wind erosion through this gap in the caldera wall.

Follow the road downhill noting lava flows exposed on the roadside, crossing the main road and continuing into Mosteiros. Head for the northern end of the main street (44.1km) where there is a café and access to the foreshore. Park and follow the coast road round to the left to a point where there are steps down to rocky foreshore.

Stop 7: Mosteiros lava delta
A dark grey, massive olivine basalt lava flow has been eroded by the sea (Figure 3). Mantle xenoliths up to 4.5cm, olivine phenocrysts up to 0.75cm and rare syenite inclusions up to 3cm (Figure 4); the syenite was medium- to coarse-grained black and white, the mantle xenoliths showed intergrowth of olivine and pyroxene on fresh surfaces. Some weathered lava pebbles showed rusty brown altered olivines, others had green olivine phenocrysts with altered pyroxenes giving a mottled grey-pink rock. There was some columnar jointing. Those seeking hand specimens should turn right rather than left after parking the car as there is plenty of loose material available.

Figure 3. Mosteiros Beach.

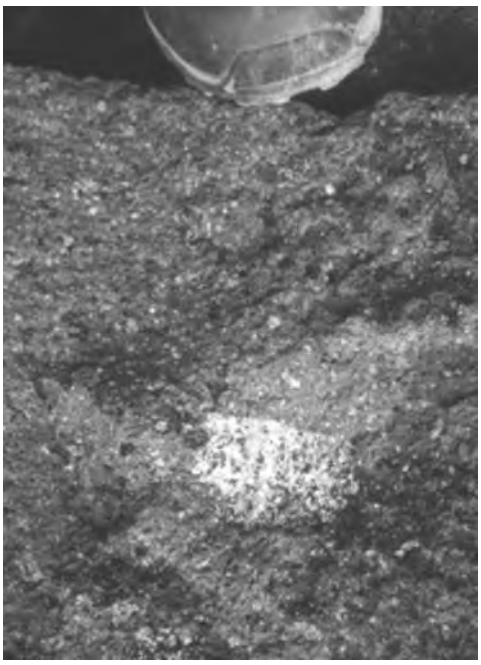

Figure 4. Syenite inclusion in olivine phyric basalt of Mosteiros lava delta. Toe of boot for scale.

Return to Porto Delgada along the coast road past the airport to Ponta Delgada. There are cafés at Varzea.

Day 2 morning - Visit to University

Roger Baker, Tim Legood

On the Thursday morning we had been invited by Adriano Pimentel, of the University of the Azores in Ponta Delgada, to visit its Volcanology and Geological Risk Evaluation Centre. Although this Department teaches some undergraduates, its main role is in monitoring and researching into the volcanic activity throughout the island archipelago. We were conducted around the various facilities by Adriano and his colleagues.

We first visited the Seismic Monitoring Laboratory, to which signals from the forty-seven permanent monitoring stations throughout the islands are fed and recorded on computer. The previously used paper recorders are maintained purely for educational (schools) purposes as the moving pens appeal to the youngsters. Although things were quiet at the time of our visit with about seven quakes per day, up to twenty signals in ten minutes had been recorded during a six-month active period in the latter part of 2005, with the largest tremor registering at 4.3. By overlaying the records of signals from different stations, it is possible to work out the epicentre and magnitude of each tremor, and gradually build up a picture of movements within the magma chambers. The signals are compared with the actual experiences of people living in the towns and villages.

Other monitoring is carried out at six permanent locations to measure the flux of H_2S and CO_2 from fumaroles. This requires considerable processing to compensate for changes in temperature, pressure, wind and rainfall before changes in volcanic output can be assessed. Measurements are also taken of water level and temperature in five wells. All of this data is subjected to statistical and modelling analysis to see if variations are linked in any way to seismic activity, and ultimately to see if any predictive properties can be isolated. An ancillary, but very important, aspect of monitoring CO_2 is in identifying localities where build up of

Figure 5. Portable gas monitoring equipment contained in a backpack; the small cylindrical container gathers gas seeping from the ground which is analysed and the concentration measured.

the gas can become dangerous, in some cases as much as twenty per cent, where it seeps into houses (Figure 5).

We then moved on to the laboratories where some of the more basic analysis is carried out, more as a background function as most resources are put into monitoring activities. Currently studies include work on the 1630 Furnas eruption, to look at its history, format and composition. We were also shown examples of lava bubbles – very fragile gas-filled balloons of 40cm or so diameter coated with a thin basaltic crust - which had erupted under water, expanded and floated to the surface. These had been recovered from the latest 1998-2001 undersea eruption. Also on view were samples of deep sea corals dredged from the Mid-Atlantic Ridge (Figure 6).

The last major area to be visited was where the monitoring equipment is maintained and new equipment developed and constructed. Even in the Azores, field station equipment has a habit of "disappearing", so much effort is devoted to developing cheaper, more rugged items for use. A most impressive aspect of the work here is the development of a straightforward seismic detector that can be produced in quantity and installed in schools. This, with an accompanying video presentation, can form a very relevant aspect of teaching the young their natural environment.

Figure 6. Sample of deep water coral from the Mid Atlantic Ridge. Specimen is about 20cm across.(LF)

All in all, we were given a privileged opportunity to see some of the activities that go on to follow up basic geological field work and we had a fascinating morning looking at the workings of a university department. We certainly learned that there was no shortage of geohazards in the Azores and were all extremely grateful to Adriano and his colleagues for their patience and enthusiasm in explaining their work to us.

Day 2 afternoon - Picos Region

David Davies, Nicki Fowler, Gary Lampon, Susie White

Following the university visit Adriano offered to show us some exposures within Ponta Delgada before we explored the Picos region in the afternoon.

Stop 2.1: Mae de Deus scoria cone

Heading south-east from the Ponta Delgada University campus and turning left towards the city centre on the road Mae do Deus, brings you to a scoria cone with a church (Figure 7) built on top. The steps to the church are of ignimbrite with fiammé (Figure 8) and the views from the top quite commanding.

Stop 2.2: Lava tubes in the António Borges garden

Some of the group also went with Adriano to the António Borges garden about half a mile to the west where there are numerous examples of lava tubes that were turned into grottos, some with lakes, during the 19th C.

We met up again after lunch and were promised an afternoon of the scoria cones and tuff rings that built up the waist of the island joining the two volcanic regions at either end. Scoria cones are straight-sided accumulations of loose cinders, and tuff rings are Surtseyan, ejected through water and lithified.

The stress pattern due to the underlying Terceira Rift that separates the Eurasian and African plates has resulted in extensive

Figure 7. Mae de Deus church: black lava and whitewashed walls are typical Azorean architecture (LF)

Figure 8. Fiammé on Mae de Deus steps (LF)

faulting and fracturing across the island, with sinistral strike-slip in the ones that align from north-east to south-west, and dextral strike-slip in the ones aligned from north-west to south-east.

The cones were formed from fissure eruptions along these fracture lines, and look from viewpoints of altitude like the work of single-minded and very large moles.

We took the road north towards Capelas, the EN 4-1a. This passes a large scoria cone with its top blown out, charming hydrangea hedges, and the tear-provoking fresh odour of cattle manure.

Stop 3: Cone alignments near Serra Gorda

5.4 km out of Ponta Delgada there is a landslip on the left and scoria cones on the right. A satellite dish lies down in the pastures to the right, and can be easily missed. The aligned scoria cones (Figure 9) vary in shape and size, some form crescents, and to those of us who remember the Muppets, there was one cone that looked just like the head of Ernie in the duo Bert and Ernie. His head was the same oval shape, and had a tuft of hair just with the same profile as the clearly defined tuft of trees growing right on the top of the cone.

Interestingly enough, when the road took us round to a view behind the cone, the tuft became even more similar as it was only a narrow Mohican style row at that side of the cone. And this was before we had had any beer. Some of the other cones had V-

Figure 9. Line of cones erupted along a fissure; Sete Cidades stratocone behind them in the distance and satellite dish for location.

Figure 10. The road to Capelas Harbour offers a section through a tuff cone formed by a Surtseyan eruption. Until the ban on whaling Capelas earned its livelihood by whaling from open boats.

shaped dips in their summits that seemed to be in alignment with the fissure from which they grew, but this is a subjective opinion only. After about 10km we reached Capelas, a delightfully faded and natural looking place, with a nice round little roundabout, and lots of bunting on display. The little bay here is made of the sides of a tuff ring, and is reached down a side road signposted to 'A Vigia' off the 'Rua da Couzeiro'.

Stop 4: Capelas harbour – tuff ring

Our convoy did some synchronized parking in the A Vigia café car park ($^{6}15^{309}\ ^{41}89^{009}$) by the tuff ring. The sides of the tuff ring were exposed as cliffs (Figure 10) around the bay and the wonderful variety of depositional features led to many exclamations of geological enthusiasm. There were bomb sags of all shapes and sizes, in some the bomb had broken already lithified layers in its journey, and one where the bomb had split in half on impact. (Figure 11)

There was a great variety of layers, the finer ones being more resistant and protruding further than those of coarser material. Reverse grading of layers showed where the pumice being lighter had floated on the top of pyroclastic flows.

On the west side of the bay the layers appeared brown in colour, but on the south side they were black. Also on the south side there were the obvious deformations of slumping and channel-cutting.

Figure 11. Split bomb, Capelas tuff ring.

Figure 12. One of the many channels in the section. This is at the lower end of the harbour road.

Walking down the bay road takes you down in time in the tuff ring, and by the boathouse near the bottom there is a whole section with massive channel fill (Figure 12), containing whole large chunks of lithified strata, broken in some explosive event and buried in random positions in the ash flow.

And a new word, for me at any rate: 'interdigitisation', which could be seen in places where later flows had punched in between earlier lithified layers forcing them up in a dog-tooth pattern – canine interdigitisation perhaps?

At the end of the bay road the cliffs overhang, and exposed bombs hang out of the layers, defying gravity and your own common sense as you walk underneath. A little footbridge carries you on to the end of the reachable section, and to my mind anyway, this seemed to be the central part of the tuff ring, because all the layers were made of coarse rubble, with no fine layers. They also seemed to be quite regular in depth, as if formed by regular and consistent pulses of activity.

Wandering back up the circular road to the car park we found other party members already drinking tea and beer at the little café. The owner apparently had plans for greater things and was outside painting walls and stones with white paint, also spattering the pavements less intentionally.

In fact at one point he came over and asked us to move from our seats, because he had recently painted it, not that he was concerned about the possible damage to our clothes, but because he didn't want dirt in the paintwork before it was properly dry.

Also here was the wonderful sight of an old whaling boat cut in half, and stuck in the ground, both halves upright to make public toilets. Naturally we all had to try these out. They were neatly painted in white and blue, with an antique wash basin to serve both in the open air between the two halves.

We left Capelas at 5pm, joining the main road out of town, and having a good view of the line of fissure cones (Figure 9) that we had passed earlier that afternoon.

We headed east on the EN 1-1a towards Rabo de Peixe. After about 6.5km from the amazing boat toilets, we reached Fenais da Luz, and a couple of kms further the village of Calhetas, with more spectacular views of the scoria cone fissure spine of the island. This next bit is a set of instructions given by the drivers Dave and Gary – at 9.6km from the boat toilet, on the road to Pico da Pedra, turn off, then left at the next junction, and at the following T junction turn right to Ponta Delgada at 30.4km from origin onto the EN 3-1a. Hope I got that bit right!

Stop 5: Rosto do Cão

This road heads south-west and brings you to Sao Roque with an enigmatic tuff ring forming a cliff along the coast, backed by a car park and friendly bar.

The enigmatic bit is that there is part of it off shore but the direction of dip of the layers is at odds with that expected by the angle of curvature of the cliff section, this is best thought about by sitting on the cliff top with a cold beer. Inspection of the layers showed small olivine crystals in basalt, probably from the existing rock as it was erupted.

Day 3 - Lombas and lavas

Naomi Griffiths, Frances Kirby, Jenny Parry, Sally Edwards

Day 3 involved a lengthy trip along the south coast to the eastern end of the island, returning along the north coast. Head out from Ponta Delgada on the dual carriageway towards Ribeira Grande. Stop in a parking bay on the left hand side of road at 26.4 km.

Stop 1: Viewpoint overlooking Ribeira Grande

View lines of cones in the Picos region and beyond them a distant view of Sete Cidades at the north western end of the island. The cones have a NW-SE lineation and have been divided into three age groups, although exposures are scarce, so dating of some is uncertain (Figure 9).

Continue on the coast road, which is very scenic and winding at height. (At 6.7km from Stop 1, there was an unexpected diversion down through Sao Bras, ending at 7.7km from Stop 1). Continue on coast road and look out for tea plantations in the region of 8.6 km from Stop 1.

Continue through Furnas and take the road towards Povoação stopping in some rather parsimonious parking on the right hand side of the road on a blind bend in Lomba do Cavaleiro (56.5 km) $^{6}52^{805}\ ^{4}178^{912}$ *to view Povoação caldera*

Stop 2: Miradouro Lomba do Cavaleiro

View of coast cliffs, Povoação old shield volcano (Figure 13) and some later ignimbrites. The southern side of the caldera is missing, due to ?landslide, ?fault, ?erosion. There is evidence of later stream erosion. Note that villages are built in line along the ribs of flows from the volcano (lombas). There have been post-caldera eruptions, probably along the ring fracture around the rim. Bodes

Figure 13. Showing the outline of Povoação caldera, together with the "missing" south side (refer to text).

2 is the first cone to the left of the missing south side and is composed of trachyte. Ferreira cone is possibly andesite, and there are other cones arranged around the rim, some basalt and some andesite, indicating discrete eruptions.

At 60.3km park in car park situated on harbour wall and walk back along seafront in a north-westerly direction towards cliffs on the left side (facing the town with the sea at the back).

Stop 3: Povoação
View a palaeovalley filled with Povoação welded ignimbrite erupted from Furnas, resting on fluvial gravels. Duncan *et al.* (1999) have described these as ignimbrites emplaced by a large trachytic eruption from Furnas volcano. The lithologies they identified are:

• lapilli beds

• thick surge deposits

• massive welded & non-welded ignimbrites

(Site 62 in the paper by Duncan *et al.* (1999))

Continue on small road between Povoação and Faial da Terra, along which poorly-sorted debris flows are visible in the road cuts. In Faial da Terra there are large cliffs showing evidence of massive landslip. Most of the material appears to have been washed away and re-worked by the sea. Up the road from Faial, there are small dykes with cooling fractures on the right hand side in road cuts. Rejoin the main road towards Nordeste and stop at Miradouro da Punta da Madrugada $^{6}63^{156}\ ^{41}83^{571}$, 26.3km from Stop 3, 86.6km total.

Figure 14. Photo of exposure at Povoação.

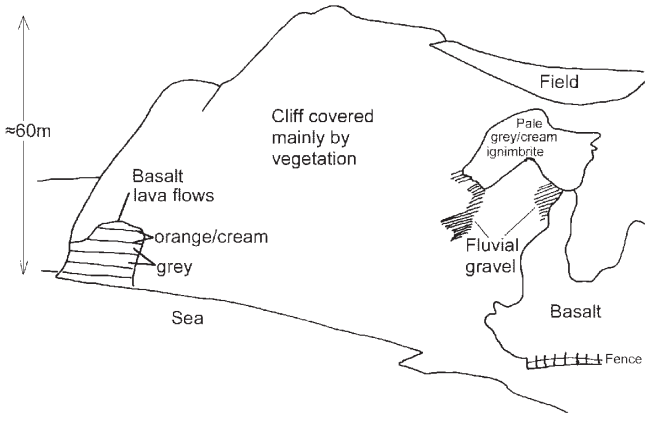

Figure 15. Diagrammatic representation of Figure 14.

Stop 4: Mirador da Punta da Madrugada
(Recommended as lunch stop in any weather, gardens and loos). Excellent views of high cliffs with exposures of Nordeste basalts.

Drive on to Nordeste village, pass through and follow signpost towards Ponta da Ribeira. At 96.8km, (10.2km from Stop 4) turn right and drive down very steep, narrow road, signposted to natural bathing pools below.

Stop 5: Ribeira de Guilherme
Looking east from car park at the bottom, view columnar jointing in massive Nordeste basalts. Walk past pools and view cliffs over river and along river bank – a series of massive basalt flows with rubbly tops and bases, with a thin dividing layer of fine clayey material, probably ash fall deposits. Olivine and pyroxene crystals and feldspar laths are evident in the basalts.

Enjoy a swim in the pools and find hand specimens in the pebbles by the river!

Drive north 21km along the coast stopping at a Miradouro at watermill with parking on the right $^{6}52^{378}\ ^{41}89^{232}$ (117.8km)

Stop 6: Ribeira dos Caldeiros (just before Achada)
View the road cutting which shows basalt lava flows, layered pink and brown ash deposits and a red horizon that may represent a palaeosol. The basalts contain crystals of olivine and pyroxene

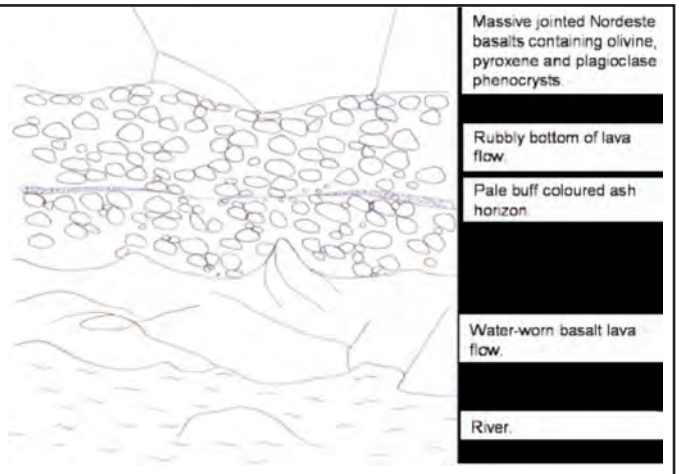
Massive jointed Nordeste basalts containing olivine, pyroxene and plagioclase phenocrysts.
Rubbly bottom of lava flow.
Pale buff coloured ash horizon.
Water-worn basalt lava flow.
River.

Figure 16. Diagram showing detail of Nordeste lava pile at Ponta da Ribeira.

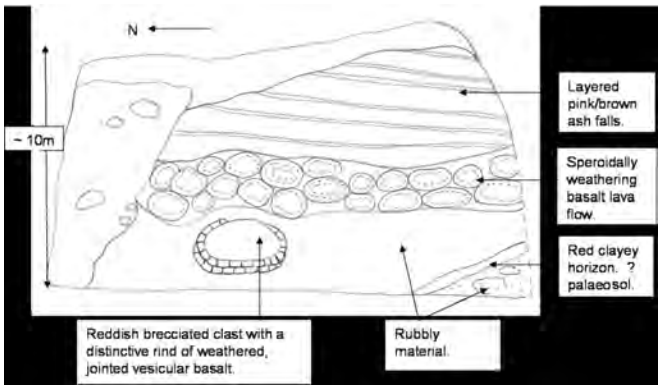
N
~ 10m
Layered pink/brown ash falls.
Speroidally weathering basalt lava flow.
Red clayey horizon. ? palaeosol.
Reddish brecciated clast with a distinctive rind of weathered, jointed vesicular basalt.
Rubbly material.

Figure 17. Diagram of the road cutting at the Watermill Miradouro.

Figure 18. Panorama of Furnas caldera from Pico do Ferro

and there is obvious spheroidal weathering of the basalt lavas. Ferny dendritic black manganese deposits are visible on some of the joint surfaces.

There is a small café here and walks in the valley by the restored water mills

Continue for another 17.9km (135.7km) through Lombhina da Maia and stop in a miradouro on the right

Stop 7: Ponta da Maia viewpoint
On coast road, just past Lombhina da Maia, looking towards Ponta da Maia, view spectacular ?raised beaches, indicating changes in sea level or possible uplift.

Day 4: Furnas volcano and caldera

Trevor Field, Bert Newitt, Julie Newitt, Colin Rownes
The weather was cool and cloudy following overnight rain. Departed Casa Do Jardim, Ponta Delgada at 09:30 hrs, accompanied on this leg of the visit by Adriano Pimentel from the University of Azores.

Take the road EN2-1a from Porto Formosa towards Furnas. About 7km along the road there is a road sign for the Golf Club entrance on the right hand side, Take the right hand turn about 300m past this toward the Pico do Ferro (signposted with a brown sign). Follow this road to the miradouro and park in the car park. No facilities at this stop.

Stop 1: Pico Do Ferro for an overview of the Furnas Caldera Area
A southerly panorama of the Furnas caldera (Figure 18) giving a view of

- 1630 eruption dome and pumice ring
- 1439 eruption dome and pumice ring
- Furnas village built over the site of the 2000 year old Furnas C eruption.
- The fumarole field in Furnas village
- Inner (younger) and outer (older) caldera walls
- Lagoa das Furnas
- Fumarole field on the lake shore

It can be noted that since the original caldera collapse event there have been ten further episodes of eruptive activity in the caldera producing the domes and features seen. The miradouro here has been built on a lava dome which has partially collapsed into the lake below.

Lagoa das Furnas water level is approximately 80m higher than Furnas village. The lake is retained by a bank of pumice and ash and because of the risk of seismic activity in the caldera (most recent 1998/9) causing a breach in the retaining wall there is a flood hazard risk for Furnas village. Ribeira Quente sources from the caldera lake, and flows through a gap in the outer caldera wall to the sea.

From stop one turn right onto the road to Furnas village, descend into the village, follow the signs to Caldeiras and park in the Pay and Display car park near the fumaroles

Stop 2: Furnas village fumarole field
There is a café and WCs are available at this stop. Across the road you can find the fumarole field (Figure 19) and hot & cold springs (Figure 20).

The aquifer which sources the hot water is in a fracture zone about 150m below the surface. The water is meteoric water. The temperature of the water is approximately 70°C to 80°C degrees

Figure 19. View of Furnas village fumaroles.

when it gets to the surface. The bubbling in the fumaroles is not boiling but gases being released. The gases coming out of the fumaroles are mainly water vapour, sulphur in the form of hydrogen sulphide (H_2S), Methane (CH_4) and Carbon Dioxide (CO_2).

Fumarole activity is affected by rainfall, atmospheric pressure and air temperature. The fumarole activity has chemically altered lava and ash present in the field as well as depositing sulphur. On the far side of the fumarole field across the road there is a line of hot and cold springs. These can be sampled. Some of the springs are iron rich, indicated by the red orange staining; some have high dissolved CO_2 content. Hot and cold springs can be found side by side. The different properties are due to different fracture pathways for each spring.

The springs on the other side of the fumarole field can be seen in

Figure 20. An energetically bubbling hot spring.

the park sited on the right hand side just before the T-junction of the turning to Povoação and Ribeira Quente (opposite the new spa hotel). All of the springs are regularly sampled and tested as part of the volcano monitoring program of the University of the Azores.

Take the road towards Povoação from Furnas Village passing the fumarole field on the left. At the crossroads turn right towards Ribeira Quente. Follow the road down the river valley. Many springs, some iron rich; and waterfalls can be seen on both sides of the valley. There is a gap between two road tunnels where a large waterfall can be observed on the right hand side. In the village drive down to the harbour, follow the road past the harbour through the village to a car park at the very end of the road.

Stop 3: Ribeira Quente 1630 and 1997 landslips and the original rocks of the Furnas Volcano

Looking landwards from the car park you can see the landslip and scar associated with the 1630 eruption of Furnas (Figure 21). The landslip has been stable since and now has buildings on it.

To view 1997 landslip and older Furnas volcanic rocks return to the village past the harbour, turn left at the junction at the top of the village and park by the memorial on the left hand side.

A 5m thick landslip came down the tiny valley across the road to the left hand side of the houses. Two rows of houses were demolished and thirty lives lost. The tennis court overlooked by the memorial is built on part of the landslip. Walking further down the right hand side of the road you can view rocks that formed the original Furnas volcano, prior to caldera collapse, in the rock face.

Figure 21. The 1630 landslip scar.

The rocks are basalt lava flows more than 100 000 years old containing pyroxenes, olivine, and feldspars. Some of the olivine has degraded to iddingsite. Opposite the house 'Vivenda Cidade' the reddened top and bottom of a lava flow are visible. The village was celebrating the feast of Espírito Santo and a procession with music wound around the houses distributing wine and meat.

Return to Furnas Village from Ribeira Quente. In the village follow the brown signs towards "Lagoas Das Furnas", approximately along the road outside the village turn right onto a small rough road, park alongside the exposure. UTM co-ordinates 647711 4118271.

Stop 4: Furnas C Eruption ash and Pumice Deposit

The main face consists of mostly ash with white-ish pumice, of trachyte composition, deposits erupted during the Furnas C eruption event. It also contains lithic fragments. The Furnas C event was the largest eruption in the last 5000 years. The face is 7-8m high. Bomb sags are evident along with other lines of evidence that this was a phreatomagmatic eruption involving water. Stratification of the deposit is best seen on the left hand side of the face.

Return to the road towards Lagoas das Furnas, turn right and continue along the road towards the lake. Turn right at the sign pointing to "Caldeiras", carry along the side of the lake and into the car park. There is a block of toilets in the car park. Walk across the car park and through the trees to the fumarole field.

Stop 5: The fumarole field at Lagoas das Furnas

Local people and restaurants cook in pit ovens in the fumarole field. Added interest on our visit was the large marquee full of food and local products: today was the annual festival of what Adriano described as 'cooking in holes'. Deposits containing accretionary lapilli can be seen in outcrops of altered rocks.

Figure 22. Lagoa das Furnas fumarole field.

Return to the main road, turn right along the lake shore towards Punta Delgada. Then take the left hand turn towards Lagoa Seca, bear left, continue along the road and take the left fork signed "Mariaconas dolmiho" Drive up the hill through a cutting and past the masts to the car park at the summit. This is the Miradouro do Lombo dos Milhos (corn ridge)

Stop 6: Miradouro on 1439 eruption pumice ring

The lava dome from the 1439 eruption can be viewed on the southerly side of the miradouro. The north side overlooks Furnas

Village. The miradouro is sited on top of the Pico do Gaspar pumice ring (Figure 18). A section through the pumice ring can be seen in the road cutting passed through. Note that because of the ferromagnesian rocks in the vicinity local magnetic fields are erratic and different from the general magnetic field.

Return to the main road and turn left towards Vila Franca do Campo and Ponta Delgada along the lake side; approximately 3km down the road, after an S-bend, the exposures are visible on both sides of the road. Park where convenient.

Stop 7: Road cutting showing 1630 and Fogo A eruption deposits
1630 deposits consist of a pumice layer (L1 layer) below an ash Layer (A1 layer). Access to both layers can be obtained by moving up and down the section. The L1 layer consists of un-stratified pumice and also contains charcoal fragments from plants caught up in the eruption. On the inside of the apex of the bend an outcrop of the Fogo A eruption layer is visible. The Fogo A deposit is made up of ash, small lithic fragments and pumice. It has a sand texture and is orange coloured. The Fogo A layer has been dated to 5000 years old by carbon dating and is used as the time reference layer for recent eruptions on Sao Miguel. This layer is particularly suitable for this because it is wide spread and easily identified in other areas of the island. At this site the 1630 Furnas eruption layers lie directly on top of the Fogo A deposit. There have been 10 eruptions between Fogo A and the Furnas 1630 eruption and deposits from these are missing from this site.

Figure 23. Exposure of the Fogo A and 1630 deposits.

Return along the south coast road through Vila Franca do Campo

Day 5: Whale watching and singing in the Azores

Janet Hiscott with Lynda Cornish and Tim Legood

On Sunday morning, our one free day, Lynda and I explored the narrow streets of the town before joining other members of the group for coffee on the sea front. The churches on San Miguel are dramatic black and white buildings. We popped into one to see the ornate and highly decorative altar and side chapels, all topped with an ancient painted ceiling. Visiting during the morning mass was quite an experience. The service was well attended with a congregation of all ages and the music and the choir were wonderful. Quite uplifting.

The weather turned out much better than forecasted and the whale-watching boats were taking bookings after all so, encouraged by Tim, my co-driver, the three of us booked places. We turned up, equipped with our waterproofs, which proved quite unnecessary as on arrival we were immediately dressed in full length yellow oilskins and orange life jackets. This should have warned us of what was to come!!

During the first hour we saw a flying fish which stayed aloft for quite a distance – an amazing sight. We then found and followed a pod of dolphins for about 20 minutes. Responding to a message from the observer based in one of the old whaling towers on land, we then turned west, into the wind and the waves, in search of a whale. This was when we learnt why we had been kitted out in the all-encompassing oilskins. By the time we eventually returned to land, we were completely drenched. An exhilarating ride, but although we stayed out an hour longer than planned, the whale remained elusive.

Day 6: Agua de Pau region (Fogo)

Phil Robinson, Greg Thomas, Martin Wass

Pick a day when the radio masts at the top aren't hidden in cloud, otherwise you won't be able to see anything when you get there! Take the main road east ER 1-1 and turn off at the Santa Cruz /Remedios junction at 14.7 km from Ponta Delgada. Follow the signs for Remedios/Lagoa de Fogo. Continue uphill to Stop 1 below the radio masts at the top of Barrosa, 23.5km from home.

Stop 1: Barrosa
Cool and windy by the radio masts with good views of Ponta Delgado. The lines of cones in the 'waist' of the island could be seen clearly with both coastlines in view. Parking was good with plenty of room for the convoy and a coach.

Another viewpoint 200 metres further on downhill with a good high level view of the Fogo crater and lake had more limited parking facilities. A 3rd view point gives panoramas to the west and north and a 4th looks again at the crater and lake. Stop 2 is 2km from the radio masts (27.3km) with good parking.

Stop 2: Fogo caldera information board
There is an information board at the end of the pull in on the right. The Lagoa de Fogo within the inner caldera is the site of the 1563 eruption. The inner caldera has a scalloped edge with the outer caldera, the Serra de Agua do Pau Massif beyond. Fogo has erupted seven times in the last 5000 years, the latest in 1563. Across the road to the left there are good views of Ribeira Grande and a sight of one of two geothermal power stations on the island. It is possible to walk down to the caldera lake from here.

2km further on at 27.3km there is a viewpoint with adequate parking above the geothermal power station seen previously.

Stop 3: Viewpoint above geothermal power station
Downhill about 20-30m on the other side of a bend in the road is a 3D exposure of pyroclastic flow deposits with cross bedding and clear lateral variations.

The power station entrance is on the right further downhill at 28km. A long driveway of about 0.5km leads to the power station itself where there is good parking. Information leaflets of good quality are available from the central administration block and there are numerous information boards around the power station giving details of the power generation, output, details of the aquifers, temperatures involved and details of the local ecology. Near the entrance is a small gate (key from admin block) leading to a raised walkway surrounding the station. This walkway is a 'nature trail' with individual plants identified and labelled as well

as information about the power station. An enjoyable and informative stop.

A further 2km downhill at 31km from the start the entrance to Caldeira Velha is on the left at the apex of a right hand hairpin bend. Parking looks hazardous on the inner edges either side of the bend but it is sufficient for coaches and heavier vehicles.

Stop 4: Caldeira Velha
Caldeira Velha itself could be Jurassic Park with giant tree ferns, waterfalls and even a mudslide into the stream at the bottom of the canyon. Large bright green frogs and giant tadpoles inhabit the stream. About five minutes walk on the path into the park is the hot waterfall and pool. Some members of the group took the opportunity for a swim in the pool (Figure 24). Just before the hot waterfall, there are hot springs, mud pools and fumaroles. Under a rock nearby a good example of sulphur crystals growing by a hot gas vent.

Figure 24. The warm bathing pool at Caldeira Velha. (LF)

Continue downhill to the crossroads, straight across and into Ribeira Grande for lunch at the A La Bote Restaurant on the sea front (excellent) to the right of the river. Following the one way system through Ribeira Grande can be confusing as you pass the same Supermarket at least twice. 38.3km on odometer.

A good stop for lunch whether you want to eat well at the restaurant or just enjoy the views of surf and sea.

Retrace your route to the main town square and head east and turn right at about 40.5km onto road signposted Monte Esauro, Caldeiras and Lombadas. Stop in Caldeiras town square (limited parking) at 44.2km.

Stop 5: Caldeiras
The town is currently more or less derelict but it looks as though refurbishment is taking place. The warm pool itself is a cloudy blue (bottom is ash with visible vents) and the area has both hot and cold running water essential for the village laundry to the side of the village square.

After exiting the village, bear left at the junction (48.5km) and continue up the mountain road over the flank of Fogo for about 8km (56.3km). Depending on time, a short visit could be made to Lombados to see the natural CO_2-rich spring and bottling plant. At $^{6}40^{047}\ ^{41}79^{935}$ turn right at a small roadside hut onto an unmade track. Continue on this track for about 1km and park immediately before an avenue of conifers at $^{6}40^{298}\ ^{41}79^{224}$.

Stop 6: Lagoa do Congro
Walk across the field to the left past a barn and follow the track for about 150m round a hairpin, and the green coloured Lagoa do Congro, a maar or flooded vent, is visible below. This maar is enclosed by a tuff ring and was created by a flank eruption after Fogo A. At this point on the left, is an exposure about 20m high and perhaps 60m long with alternate layers of pumice and ash with large lithic blocks up to metre dimensions. Evidence of deposition followed by erosion and further deposition. The Lagoa do Congro is about 80m below this point and was not visited.

Returning to the vehicles, continue on the unmade track to the 'main' road about 1.5km further on and turn right (57.9km). At 60.8km at the bottom of the hill turn right in the direction of Vila Franco do Campo. Almost immediately turn left direction Ribeira do Tainhas/Ponta Garea. At 62.2km turn right to Ribeira do Tainhas. Opposite church turn left to a Miradouro with good parking and possible refreshments. (64km).

Stop 7: Ribeira do Tainhas beach
Below the Miradouro is a cave on the beach where the rubbly material and palaeosol between lava flows has been preferentially eroded out by the sea.

Exiting turn left at the church and left again at the main road at 65.5 km and straight ahead at the roundabout (67.2km).

At 71.3km between Agua do Alto and Ribeira Cha there is a large car park adjoining a splendid sandy beach and the Wave Bar. Very suitable for late afternoon refreshments and generally winding down.

Continue a kilometre along the road (72.5) on the right hand side pull in to good parking.

Stop 8: Ribeira Chã
An exposure of the Ribeira Chã eruption sequence with many examples of fiammé: ejecta that have been deformed by compaction into lens shapes while the flow was still hot. Many lizards on the exposure. Continue on this road back to Ponta Delgada, a 93km round trip.

Many additional places could be visited including the village of Vila Franca do Campo where there is a good view of an islet, a perfect tuff cone. From Ribeira do Tainhas to Ribeira Cha there are many exposures of material washed down from the volcano in the 1522 landslip. Most of these are now netted and bolted to prevent the road being blocked.

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Book reviews

Tectonics of the Western Mediterranean and North Africa by Moratti G & Chalouan A (eds), 2006, Geological Society, London, Special Publications, 262, 392pp, £85 (£42.50 GSL) (hardback) No paperback price yet, ISBN-10: 1862392021, ISBN-13: 9781862392021.

I had noticed this book in GSL listings, so was pleased when I saw it for review. I visit southern Spain frequently and was keen to read more about the tectonics of that particular bit of the western Mediterranean: the Spanish Betic Cordillera especially.

I was a little disappointed therefore to find (as might be expected considering the editors locations if I'd thought about it!) that despite the publisher's blurb referring to 'Maghrebian chains in North Africa, … Tunisia to Morocco … Western and Central Mediterranean … Spain to Italy … pre-orogenic phases (Palaeozoic-Mesozoic) … post-collisional neotectonic and Quaternary development … aspects of structural, sedimentary, metamorphic and marine geology' the majority of papers dealt with Morocco or Italy, only touching on other areas.

The book, as is usual for this series, is a collection of papers around a theme. There are 22, mostly based on work in Morocco or Italy (including a large, full colour 1:50 000 geological map of the Sant' Arcangelo Basin in Italy's 'instep') but with some 'outliers' – central Tunisia, the Betics, the Tagus basin in central Spain, and early Alpine red beds (Verrucano). Tectonically the Western Mediterranean is a very complex ocean remnant caught up in the Alpine Orogeny, as you might expect from the mountain chains encircling it. From the title, I had expected more about the Mediterranean basins in the area – the Tyrrhenian Sea is covered but there is less about other offshore tectonics.

However, once I had got over the initial frustration that information about my local area wouldn't be handed me on a plate I found the book more interesting. The Moroccan Rif mountains are a southern 'mirror-image' of the Betics, the whole forming a horseshoe around the Alboran Sea with the Straits of Gibraltar midway. Anything to do with the Rif could have analogies in the Betics so Moroccan papers covering sequence stratigraphy in turbidites, synsedimentary tectonics, fold development in the Prerif Ridges, tectonic wedge escape, nappe emplacement, thrust sheets and so on held more interest for me than the Italian papers.

In summary, 392 pages, plenty of figures, including colour ones and the map but, like all GSL publications it doesn't come cheap, especially in hardback at £85 (£42.50 for GSL members though including Candidate Fellows – students). Worth reading if you have interests in Italy or Morocco or if you are keen on the clues and signs left by orogenies with complications!

Linda Fowler OU tutor

Geological Journeys A travellers guide to South Africa's rocks and landforms by Nick Norman and Gavin Whitfield, 2006, Struik Publishers 320pp (softback) £19.99 ISBN 177007 062 1

This is the first edition of a book which will set the standard for any subsequent guidebooks. All the maps in the book were supplied, at no charge, by the Council for Geoscience and the book was sponsored by De Beers Consolidated Mines, two authoritative recommendations.. The inspiration for the book was the curiosity of non-geologist friends of the authors who returned from holidays lamenting the authors' absence when they wanted explanations of what they were seeing. The book is intended for travellers around South Africa, not to encourage detours to famous geological occurrences (although these are not precluded) so that one knows what to look for and where and how to look.

"The world in one country" can be applied to the geology of South Africa. Additionally, for a UK orientated geologist it is a twist of perspective to learn of the Southern hemisphere view of geology and their early acceptance of the concept continental drift, even if the mechanism was not understood.

The introduction is as clear an explanation of the structure of the Earth, basic rock categories, plate tectonics, timescales, landscape creation and the framework of South African geology in twenty pages as any interested amateur could hope for. Then follow eighteen journey chapters based on the main national routes and metropolitan centres. Each chapter starts with a geological overview and then places of interest with boxed sections for interesting topics e.g. the development of gold mining, discussions on the granite controversy, the nuclear industry and the footprints of Eve.

Nearly every page has at least one colour photograph, sketch, or map printed on good quality paper.

There is inevitability a number of references to mineral exploration (not just gold and diamonds) given that both the authors have spent a lifetime in that field both in South Africa and elsewhere and run separate geological consultancies. Nick Norman is a past secretary of the Geological Society of South Africa (GSSA) and Gavin Whitfield is active on the Conservation Committee of the GSSA.

The book concludes with a four page glossary defining about 250 technical terms, a bibliography and an index listing around 400 topics from Accretion and Acid rocks to Zirconium and Zululand Group. It was good to be reminded of the geology I once understood. I found this book to be very readable, accurate, well illustrated and whilst aimed at the interested amateur did not avoid tackling serious geological topics without being patronising. I would recommend it as an introduction to the geology of South Africa for anyone going to South Africa and for anyone who wishes they could go.

Peter Greaves BSc

London Branch visit to Shetland 31 July - 7 August 2006 leader Allen Fraser

Maggie Morley, Gillian Hetherington, Peter Franklin, Bob Morley, Heather Rogers, Ursula Scott & Les Richmond

Day 1

Our comfortable overnight ferry trip from Aberdeen to Lerwick was an excellent start to LOUGS visit to Shetland. It may have been misty as we all enjoyed a leisurely breakfast on board, but by the time we had disembarked, raided the Coop for lunch and had a dodgy tyre changed on the mini-bus (the Paddy Wagon), it was sunny.

Scalloway, on the west coast, where we were to stay at the North Atlantic Fisheries College was only a few miles drive from Lerwick. Shortly before reaching the town, was a viewpoint from where we could see all of Scalloway beneath us - the harbour with its old houses round it, new marina, ruined castle and the NAFC buildings nestling low on the shoreline.

After leaving luggage behind at NAFC our convoy of three vehicles led by our guide Allen Fraser set off for Sumburgh Airport to pick up more arrivals. Several people had been delayed due to the earlier mist. Nearby Sumburgh Head Reserve made a wonderful spot for our picnic. Sunshine, lighthouse, cliffs, sea breaking over rocks made a wonderful backdrop for watching gannets, skuas, terns, puffins and even a basking shark.

It would need a small book to tell the story of the Broch and Iron Age Village we visited at Scatness where we spent a very interesting couple of hours. The onsite guides were very enthusiastic and were happy to answer our many questions about the settlement which has been occupied for 2000 years. The Broch, a double-walled tower was probably for defence and the roundhouses and wheelhouses were built around it at later times. The dwellings were those of Iron Age people, followed by the Picts and later the Vikings. The whole area gradually fell into ruins and became covered in grass and buried from sight till a new road was being built for Sumburgh Airport. Excavation only began in 1995.

Back to our lodgings to unpack and freshen up before dinner at Da Haaf the NAFC restaurant where the fish was delicious. The evening sun cast a warm light over the water and headlands creating a very attractive vista to end an enjoyable day.

Maggie Morley

Day Two

Location One: Scord Viewpoint. The view was stunning, if a little misty, with mountains and valleys and the surrounds of Scalloway before us. This was a stop to set the scene in geological terms for the rest of the day and to some extent the rest of the week. Allen introduced us to the names of major rock groups and types and the tectonic episodes which were the most significant events that shaped the current topography of the Shetland Islands.

The major rock group around the area is the Clift Hills Division including the Clift Hills Phyllite which, locally occurs in various colours due to the variation in the mineralogical content of the rocks, and has a dip which is near vertical. We could see this at a distance in the massive road stone quarry which dominates part of the skyline of Scalloway. The origin of the rocks is Pre-cambrian sediments which have been metamorphosed and folded during the Dalradian, some 400 to 600Ma. It is quite impressive to think that these rocks have been around so long and changed so much. The topography as seen from the view point has been shaped by the erosion of limestones in the valleys leaving harder and more resistant hills of the phyllite and of granite intruded around 500Ma, such as the Hill of Berry.

The Tingwall Valley with Scalloway at its end marks the line of the Nesting fault which is thought to be part of the Walls boundary fault, part of the Great Glen Fault system. Up to now these had been words on the page but to see them for real was a treat and indications of what was to come.

Location Two: Black Gaet Junction. This stop was a road cutting approximately four metres high and a few hundred metres long. This was our first chance to look closely at the Clift Hills Phyllite and get our hands and our eyes on the rocks. The drivers of the traffic going past looked with surprise at us wearing our yellow hard hats, but they did not stop to ask what we were doing. The rocks were as interesting close-to as they had looked from a distance. They were predominantly phyllites with darker bands of micaceous material, probably metamorphosed muds and some lighter layers which were probably metamorphosed sand and some bands of quartz. The original rocks derived from extensive weathering, transportation and deposition of sediments as submarine fans or in deep basins. What was even more interesting was the evidence of the complicated life undergone during the metamorphic processes which produced the rocks that we were looking at today. Prompted by Allen we searched for and found strain bands crossing each other, fine scale crenellations and kink bands and, within the layers of quartz, boudinage structures (Figure 1). It was an excellent chance to see for ourselves some of the features of metamorphic rocks that we had only previously read about.

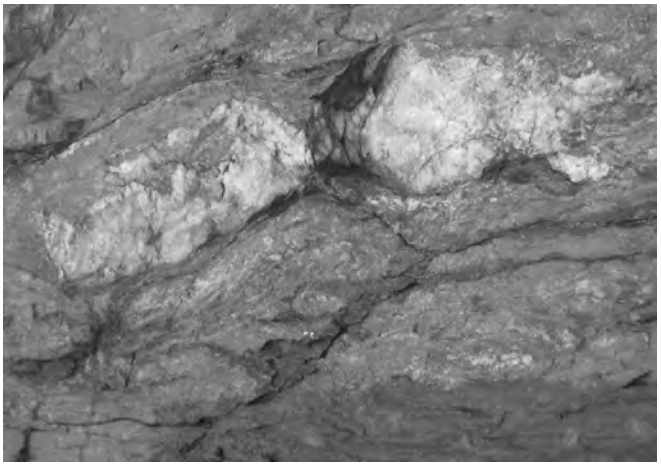

Figure 1. Black Gaet Junction - Clift Hills Phyllite showing boudinage of a quartz vein.

Location Three: Mail. We stopped on the road near the top of the cliff and went through the cemetery with many interesting headstones and monuments and fabulous views out to sea. We scrambled down onto the beach to look for pillow lavas. What we saw was a lot of grey rocks covered in slippery seaweed. According to the notes these are rocks in the Dunrossness Spilitic

group. Spilite is formed when the plagioclase minerals in basalt are altered by sea-water to albite. So, the tectonic setting was right, but what of the pillow lavas to go with it? To find anything at all, we had to really get our noses on the rock. We were told that there were pillow lavas so we tried our best to find them. Scrabbling around on the beach in the rain is a real sign of dedication, but we did find what could, with the eye of faith, loosely be described as pillow-lava-like structures. I am not convinced about what we saw, but we did only have a short while on the beach and maybe with more time we would have found something that was more convincing. What this site did do, was to add to the story of volcanic and tectonic activity which shaped the landscape.

Location Four: Catpund Quarry and Catpund Burn. This locality, based in a quarry, was to us the chance to look at samples of steatite, talc and serpentinite of a very special type. We parked off the road to walk up a track which had been cut around 1987 with a view to the commercial extraction of talc. Once again in 1997 commercial interest was shown, but the quarry is not currently worked. As we walked up the track it was hard to know what to look at; where our feet were going so that we did not stumble, or at the amazing rocks shown in the cutting wall. All the rocks within the Dunrossness spilite group that were mentioned in the notes were there; we were able to see the steatite with a thin black layer of metasediments of graphitic phyllite and the paler bands of steatite. To touch, the steatite was smooth and silky just like the implements that we had seen carved from it at the old Scatness site the day before. The quarry, when we reached it, was small and it was difficult to see how it could have been exploited in any commercial way but the rocks were very interesting. We could examine them close-to and came to the conclusion they were an example of the very special rock that we had been looking for. We could see its brecciated nature, originating at the time of its formation, and the random spinifex texture of the serpentinite crystals without the aid of the 'eye of faith' and almost without hand lenses; we spent a long time looking and marvelling at these rocks. The observations are so special because, taken together they are indications that the rock was originally laid down as a sequence of komatiite lavas. Allen's notes gave us a very succinct explanation of komatiite lavas, "these represent ultra-basic, olivine-rich lava flows that were erupted at very high temperatures (near 1600°C) from deep within the mantle". The extraordinary thing about this occurrence of the rocks and the cause of much discussion among us and the experts too is the fact that they are extremely rare in rocks as young as Lower Ordovician. There is a very good explanation about why they might have occurred here in Allen's notes which I do not have the space to include. We were very interested in these rocks, but had to carry on up the track to go on to the next site.

The next visit involved quite a scramble up to the Burn of Catpund to see evidence of exploitation of the rock that had been successful rather earlier than the 20th century. This was a fascinating site in which we could see the old spoil heaps and overgrown quarry workings covering the whole area. On closer inspection we could see chisel marks on the exposed rocks and hollows in the ground where the steatite (also known as talc-magnesite, soapstone or 'clebber' in Shetland) had been worked by the Norse people who lived in the islands after the Iron Age. Norse people used the steatite to make cooking vessels, lamps and all manner of other useful and decorative objects. We had seen some of these objects during our visit to Old Scatness (Figure 2) and it was very interesting to see the source rock for the objects that the Living History group were recreating in the same way that the Norse people had done so long ago. It was another treat to visit this site and appreciate how the lives of the people were so closely linked to the geology. I would like to have spent more time exploring the landscape and looking at the rest of the settlement but it was lunchtime and we returned to the vans and went off to lunch and mull over all that we had seen so far.

Figure 2. Soapstone implements made by living historians at Scatness archeological site.

Location Five: Maywick-Taing. This time we had some work to do with a beach section to study, discuss and then explain. It was still dull and drizzly as we walked down onto the beach, but this did not dampen our enthusiasm for the task in hand. The first rock to find was the 'hologram rock' so called because as you pick it up and move it around the pattern on its surface changes as the light highlights the differential foliation. This is caused by the multiphase deformation of the rock into phyllite, slightly more schistose than some we had previously seen. Handsome samples were found, duly admired, photographed and picked up to be taken home as specimens. The next exposure was further along the beach across a stream which was flowing fast and looked more the colour of beer than water as it made its way from the peaty land across the beach to the sea. Where the stream went into the sea it too turned brown, this time, the colour of chocolate. But what of the rocks? The first part of the section was made up of layers of quartzite of various thicknesses and shapes directly associated with some discontinuous layers of shale. The discussion about the deposition of the original sediments suggested deltaic or maybe braided streams with some of the quartzite being altered channel fill with clay drapes. Closely associated with these layers were many quartzite bands and brecciated layers indicative of episodes of tectonic activity. We looked for and found evidence of folding, compression, extension and faulting, further evidence for more than one phase of tectonic activity. Taken together we were able to use these observations as clues for interpretation of the next part of the section further along the beach. At first sight we saw a large orangey brown amorphous mass with no sign of any

structure. Close-to, the rock looked like iron-rich sediment, but how could there be sediment in an area so obviously altered? It did not seem to fit with what we had seen already. The answer was suggested by the tectonic activity. We were looking at large blocks of quartzite which had been altered and dissolved by the action of hydrothermal fluids, hence its soft and crumbly texture and apparent sedimentary nature in an area dominated by metamorphic rocks from many phases of tectonic activity. It was a fascinating and stimulating site which generated lively discussion at many different levels.

Figure 3. St Ninian's Isle tombolo.

Location Six: St Ninian's Isle Tombolo. We stopped in a rubbly lay-by at the side of the road near Bigton towards the South end of the Island, not a very promising start. We then walked about 50 metres to the edge of the cliff and looked down on the tombolo between the mainland and St Ninian's Isle (Figure 3). This was much more impressive - it is the largest active sand tombolo in Britain with a beach length of 500 metres. What you see is a strip of sand curved symmetrically on both sides, looking in profile like a concave lens, which links the mainland with the Island. This particular tombolo has been in existence since at least the dark ages and it is thought owes its stability to the sand overlying a cobble base. Even though the tombolo remains the sand on its surface changes its profile over relatively short periods of time dependant on weather and tidal conditions. The time that we visited the weather had not been stormy so it was topped with sand with no sign of the cobble base. We caught glimpses of other tombolos during the week, but none as impressive as this one which was well worth the stop and, as stated in the notes, a fantastic photo opportunity.

Location Seven: Garths Ness. The last location of the day is hard to describe in words, but once again "spectacular" is a good starting point. We drove past Quendale and then up a rough track and parked near some derelict and scruffy MOD buildings, just left as they were when the last of the men went away, an even less promising view than the last stop. We walked along the cliff top across the ness looking at the rocks as we went. The rocks, in the Clift Hills Division, are mainly striped hornblende schists containing epidote, plagioclase, quartz, chlorite and biotite. Allen explained that these rocks were most likely to be Dalradian in age originating from an island arc environment. What we went to see was a massive zone of sulphide mineralisation approximately 32m long and 4.5m wide within the schists. This was exposed due to the entrepreneurial attempts to extract copper by Alexander Chrighton and Andrew Grierson, Laird of Quendale around 1800.

Figure 4. Garth's Ness ore body - massive sulphide mineralisation zone 32m and 45m wide within the schists.

What we saw was a large oblong, brownish body of rock with a curved surface bounded by straight lines delineating the adits that had been dug to mine the copper. It must have been a backbreaking and time-consuming job to shift so much rock to obtain copper in economically viable quantities. The men working this area seem to have been paid well for their troubles because, in order to improve the assay quality of the ore, they secreted copper pennies in the assay samples. Eventually they were found out when the ore that was sent for processing did not match the quality of that shown in the assay samples and the mine was closed down as being uneconomic. The following information from Allen's notes gives another indication of the tectonic activity that has gone into the building of Shetland. "This ore deposit consists mainly of pyrrhotite with only very small amounts of pyrite and chalcopyrite. The origin of the sulphide deposition is thought to be from a mixture of magmatic water, derived from a cooling volcanic dome and large volumes of sea-water, conditions associated with young island arcs. These deposits can often thicken and evolve to contain economic concentrations of copper, zinc, lead, barite and sometimes gold." This was a fascinating site, and like so many of the other locations covered in our first day and a half, it showed the close link between geology and people's lives.

A brilliant day despite the rain showers, finished off with an excellent meal in the Herrislea Hotel just up the Tingwall valley.

Gillian Hetherington

Day 3

Off to the far north. A day of ferry schedules and distances to cover, so a prompt start needed. No last-minute dashes for the loo, everyone was seated and strapped in at the appointed 0845 departure time.

First a dash for the wonderfully named Both of Taft for our first crossing, a grey day but the islands of Brigg to port and Samphrey to starboard to admire. Into Ulsta on Yell and a rush through a landscape of wet grassland where, I suspect, the sheep have webbed feet.

The ferry between Gutcher and Belmont was to take only 15 minutes. On to Unst, the most northerly of the Shetland isles, no need to hurry and the sun came out.

Location 1: The Wick of Skaw. A beach location at and the wonderfully photogenic Skaw granite. Bright red tabular phenochrysts of microcline feldspars up to 50mm long, contrasted starkly with the grey banded xenoliths of metasediments that had been violently gathered as the granite was emplaced.

Location 2: The Tang of North Wick. Off to see the ophiolite. Alan's wonderful field notes talk of metaharzbergite in contact with Dalradian metasediments but to my eye such differentiation was impossible and I felt that the facilities of a good Earth Science lab would be needed to work out which was which. We did have the company of seals, eider, gannets, arctic terns and, a first for me, arctic skuas when the rocks became too confusing.

Location 3: Clibberswick. A talc quarry which, unlike our visit in 2005, was not working which made the walk to the cliff top far less hazardous. A scramble down to the shore took us to a beach covered in serpentenite pebbles and an energetic time bouncing flat stones off the calm sea.

A lunch stop near the Boat Museum at Harroldswick was welcomed by all including the gulls who enjoyed the left-overs.

Location 4: Hagdale. A restored stone-built crushing mill where chromite had been extracted from a gaunge of dunite by crushing with a heavy rolled driven by a horse walking a circular path. Much debate ensued about how it all worked with may suggestions but no definitive conclusion.

Location 5: **Nikka Vord.** A group of chromite pits on a hillside above the mill and to a break-in-slope which marked the location of the MOHO after the obduction of the opholite.

Peter Franklin

Day 4

Location 1: Scord of Sound. Today was billed as a West-to-East traverse from Moine to Dalradian and back and across to the Dalradian again. The low cloud was just enough to give a true Shetland atmosphere to our first stop, a viewpoint to appreciate the way glaciers had preferentially eroded softer metamorphosed limestones to create the long low valleys and sea arms called "voes". Lowering clouds meant we couldn't see a lot of it but Allen told us the tale of a church minister who prayed for timber to re-roof his church, and the captain of a timber ship who promised his cargo to God if he and his crew survived a furious storm.

Location 2: Ward of Tumblin Quarry. On to the rocks; in a roadside quarry at Tumblin we saw dark pyroxene crystals lined up in monzanite indicating the effects of tectonic pressure, or perhaps some flow in the magma? There were certainly some pieces of serpentinite being digested. Sue found a lovely pistachio-green sample of pyroxene turning to epidote, it must have sunk towards the bottom of the magma chamber.

Location 3: Hill of Lee. A quarry at the edge of the Moine, the mist was getting wetter and colder but to compensate there was some stunning Valayre augen gneiss with huge oval crystals of microcline feldspar with regrowth shadows around them; I suspect a sample will appear at the GA rockfest in November, along with some rather fine Moine Schist from the same place.

Location 4: Kirk House. Some much-folded psammites at the next stop, some of the white lines fizzed with dilute acid, others did not, so quartz veins there as well as metamorphosed limestone. We walked down the hill through the long wet grass and were rewarded with a spectacularly boudinaged quartz dyke on the river bank, the best example in Shetland Allen said; on the far side you could see holes where the boudins had fallen out. Actually the strata was tilted vertical so the vein was concordant with it, so perhaps a sill rather than a dyke; and it was a vein so neither a sill nor a dyke.

Location 5: Laxo Shore. After lunch we walked along the shore inspecting more spectacularly stretched and folded rocks. Some tried to work out their D1, D2, D3's etc and got very tired heads; some of the white bits fizzed with acid but others did not so we had a mixture of minerals; there was a major vein standing proud which didn't fizz, quartzite, not so battered and bent, so more recent. Also some faulted psammites cross cut by similarly faulted quartzites – a bit enigmatic. Some fine examples of fault gouge too. There were red granodiorite outcrops down on the beach and Allen told us that the next outcrop of these is 16km to the north, that is the throw of the Nesting Fault which had caused all the turmoil in the rocks we had just been looking at and also the arm of the sea where we were standing. He took out the geological map and showed us that if you (mentally) slide the two sides of this fault about 16km then all the differently coloured patches on either side match up nicely.

Location 6: Drut Wick Quarry. By now the weather was turning distinctly chilly so our last stop was back with our good friend the Valayre gneiss. Large circular phenocrysts, some nicely rotated, pressure shadows, some tails like large fat tadpoles. Some parts were almost a melt/migmatite and there were some lineaments or shear zones. A variety of circumstances must have led to all this – very enigmatic; those who understood more were heard to remark that there were probably 3 PhD's to be earned in this quarry.

Bob Morley

Day 5

Northmaven

The first stop of the day was at Mavis Grind. Here the British Isles has its narrowest point. The Atlantic Ocean lies to the West of Mavis Grind with the North Sea to the east. It is possible to include both in one photograph. Here we heard stories of Viking longboats taking a "short cut". The BBC televised a re-enactment. This involved unloading the boat, carrying it over the Grind and re loading before continuing the journey. What the television programme did not show, allegedly, was the boat breaking up and the debris being cleared by bulldozers.

Locality 1: Virdins Quarry. From Mavis we walked to the first locality of the day. The safety instructions were to use the top level only as the bottom level was not safe.

Here gabbro is intruded by granitic sills. The notes suggest that the granitic veins and sills "easily penetrated the gabbro-diorite" but evidence was found of the red granitic material digesting the darker gabbro-diorite. In this situation the magmas were mixed. The gabbro was probably still hot when it was intruded by the cooler granitic magma. Amphibole needles were seen to be randomly aligned indicating a lack of pressure.

White scapolite veins had formed along faults and veins throughout the quarry. This altered feldspar was produced by hydrothermal fluids passing along the faults and cracks.

Locality 2: A roadside cutting near the Brig. Our leader described this as a geological puzzle. At the northern end of the cutting, the rock is said to be a granophyre with zenoliths of altered andesite. There is foliation in the incorporated material suggesting a folding of the country rock before assimilation. In some of the rocks there is onionskin weathering typical of dioritic rocks.

Further along the cutting "the granophyre is in contact with a band of hornfelsed schist" (an indicator of contact metamorphism). This in turn gives way to granite, and eventually to serpentinite.

The answer to the puzzle is probably in the sequence: -

1) Country rock

2) Retrogressed to serpentinite

3) Granite intruded- hornsfelsed to baked serpentinite

Lunch stop was a rock field from where (according to the notice) you can take a walk in the Arctic Circle. It certainly felt like Arctic conditions. The views were fantastic. We were able to see the most northerly point of the British Isles - Muckle Flugger.

Locality 3: The Beorgs of Housetter. This locality was omitted because someone had dumped agricultural lime. Our leader did not fancy wet lime from our boots collecting in his van.

Locality 4: the Great Glen Fault. Here we were to see the Great Glen Fault - Europe's largest tectonic feature. "The best exposure of the Great Glen Fault anywhere in the world" according to our leader.

We followed the cliff top along the headland watched by the ever-present seals. At the appropriately named Otter Hadd, an otter briefly surfaced before disappearing around the headland.

We reached the line of the Great Glen Fault. A shallow depression which could have been a drainage ditch. Some photographers used people as markers others resorted to walking poles. I doubt if any one has convincing images. A walk along the fault involved bouncing on the springy sphagnum moss and kicking up cotton grass seeds. The fault is most impressive at the small bay of Back Sand. By scrambling down a gully we could make contact with the fault with its layer of fault gouge. This has been analysed and is said to be 0.5m thick and is composed of "a hematite-stained isotropic paste containing fragments of analcite and quartz"

To the east of the fault the rocks are metamorphic rocks with folds ranging from tiny crenulations to huge structures. Interesting, dramatic and extremely photogenic and guess who hadn't got a camera!

The most exciting find of the day, for me, was the discovery of otter footprints in the sand leading to a lair. Those members of the group who stayed on the cliff tops were watching the otter waiting in the bay for us to leave before coming ashore.

Locality 5: Houb of Scatsta overlooking Sullom Voe. Here we saw evidence of a tsunami generated by the Storegga slide off Norway about 8000 yrs ago. Marine sands can be found in the stream bank. The Tsunami is thought to have been 25m high.

Locality 6: The Ayres of Swinister. This photogenic feature demonstrates local environmental change.

Heather Rogers

Day 6

Today's exercise was to examine some of the volcanics of the Eshaness peninsula. These volcanics are believed to have been caused by subduction of a small part of the Iapetus ocean crust beneath Scotland and Shetland around 360Ma ago.

Location 1: The beach at Braewick. This is on the south coast of Eshaness - a hard hat site because of divebombing terns. This site, we were told, would give us a chance for some investigative work so we set off with much enthusiasm despite the lack of any geochemical analysis to assist us. What can be said about a place over which even the finest minds are divided? The rocks comprise rubbly basaltic lava flows overlain, we thought, by tuffaceous sandstone, some andesitic lava, bombs and not a whiff of a pillow lava. A bit of a dog's dinner really which left us a bit puzzled as to what it all meant and indeed in which order events had occurred.

Location 2: The north-west coast. We walked in a northerly direction along a 2-3km traverse which crosses progressively older lava flows and represents a cross section through the flank of a volcano.

The traverse started on an andesitic lava flow. This was soon covered by pyroclastic material displaying rhythmic layering which indicates different eruptions. We examined the very deep Kim O'Slettans blowhole which during exceptional storms has been seen to produce water as high as the nearby lighthouse. The blowhole, which appears to be crossed by intersecting dykes, is believed to be a collapsed lava conduit (or were we perhaps looking at eroded jointing partially filled with fine secondary material? The jury is still out). There is some conjecture as to whether this blowhole area was once part of a parasitic cone on the flank of the main volcano.

The coastline along this traverse is simply spectacular. The battering received from storm waves is phenomenal and rock debris has been lifted and strewn along certain 30-40m high cliff tops. Deep water at the base of these cliffs, the huge fetch across the Atlantic and fierce North Atlantic storms combine to produce storm waves capable of such action. Wave action has also contributed to a coastline deeply incised by geos as well as other spectacular features such as Moo Stack. Geos are deep inlets resulting from marine erosion of the cliff face along faults and joints. Incipient geos can be seen in the form of caves and tunnels. Compressed air and water within these openings leads to block loosening, further seawater penetration and eventual ceiling collapse. Glaciation can also play a part in geo-formation.

Location 3: The Grind of Navir (aptly translated as Gate of the Borer). This was, for me, the most awe-inspiring site of the day. Our notes described it as a large amphitheatre hewn out of ignimbrite. As it stands today there is a cliff wall with a gap in it measuring 10m wide by 13m high some 12m above sea-level. Behind this cliff wall lies a quarry with a load of stone blocks waiting to be taken away. But it is the sea and not man that is responsible. Storm wave energy is further enhanced by the narrow cliff opening and produces a wave velocity sufficient to prise out large ignimbrite blocks up to 3m in length and move them 100m inland to form a storm "beach" about 3.5m high. The ferocity of North Atlantic storms is notorious but I had never imagined they could be quite so powerful or erosive.

As on previous exercises there were more questions than answers. More success was had on the animal front with sightings of an otter and several basking seals.

Ursula Scott

Figure 5. Dalsetter erratic - glacial erratic identified as Tönsbergite from southern Norway.

Day 7

Location 1: Dalsetter Broch. Our first geo stop was by the side of the road near Dalsetter Broch. It was a rounded stone unearthed in the 1930s when repairing the road. Being somewhat different to the surrounding geology it was identified as an erratic (Figure 5). It was evidence that ice from Norway had reached Shetland about 25,000 BP. The rock is identified as Tonsbergite (southern Norway near Larvik): large rectangular to rhombic white feldspar crystals with over-growths of reddish brown feldspar: of igneous origin around Tonsberg.

Figure 6. Shingley Geo - lake shoreline showing lacustrine facies.

Location 2: Shingley Geo at Broken Brough. Where we were able to see part of the Shetland Basin, well, the shoreline, made up of lacustrine environments and aeolian sandstones (Figure 6). This involved a walk down the hillside through peat-type bog down to the shoreline and the example of lake shoreline. There were three main lacustrine facies. There were sandstones and siltstones with low-angle planar cross-stratification and ripple cross-lamination in each facies along with a layer of calcareous siltstone and mudstone; typical examples of shallow seas, showing the effects on the facies by wind and currents on shallow-sea deposition.

Location 3: Ward of Scousburgh.
A very windy high point where there were spectacular views of St Ninian's Isle. And the long peninsula of the southern mainland.

Location 4: East Voe of Quarff. A small beach and a look at the Basal Breccia. Here there was an example of coarse breccia-conglomerate and the unconformity with the underlying Quarff Nappe Metasediments. The composition of the breccia showed very coarse and angular clasts cutting into the Quarff Nappe. There was also mica and the rocks had a "high twinkle factor" (a technical term used by geophysicists including learned persons within our group)

Location 5: Scottle Holm. Allen assured us there was a classic example of a conglomerate of alluvial fan and sand dykes just to the left of the scrap yard and along the shoreline. We tramped through the long grass to the shoreline (a mere 200 yards – be warned the Shetland yard is in fact 4 cubits long). A great example of a conglomerate with sand dykes, thought to have been emplaced by gas pressure along the faults and joints of the conglomerate (Figure 7).

Figure 7: Scottle Holm - conglomerate of alluvial fan, sand dyke, coastal section.

And so our week in Shetland had finished. It had been a fascinating week and complex. So much had happened amongst these wonderful Islands. The geology had one stop and think – many times. The geological upheaval that had occurred over the past 700+ million years had left a puzzle that had seemed impossible to decipher.

Many thanks to Allen for his superb leadership and also to Sue who organised the trip. Thanks to all of you! Thanks to meeting old friends and new.

Les Richmond

Orkney 9-12 June 2006

Chris Arkwright, Linda Smith, Anne Lavelle and Gerry Shaw

Day 1

After travelling to Stromness from various parts of the UK we were now being driven to the first Orkney site. Our leader, Dr John Brown, and trip organiser/driver Rachel Jackson, were keen to show us the rich heritage of their native islands, as well as the geology, and where better to start than with a visit around the most northerly Scotch Whisky distillery in the world, Highland Park!

The distillery, one of only five in Scotland where malting still takes place, stands on a hill overlooking Kirkwall and the vast natural harbour of Scapa Flow. Founded 200 yrs ago, the company still uses traditional methods and ingredients to make one of the finest malt whiskies – a statement we fully agreed with after the scientific investigation (i.e. tasting) which ended our interesting trip around the site.

But first we found out that the barley is initially steeped in water to trigger growth, thus producing the sugars which are later turned into alcohol. Then the green barley is spread out on the malting floors and turned over many times during the next 6-7 days as germination proceeds under the watchful eye of a very skilled maltman (Figure 1). After drying, the malt is then ground into grist, mixed with heated water (drawn from local springs sited in hard red sandstone), mashed and injected with yeast. Fermentation and distillation (Figure 2) follows and finally the distillate is stored in casks until the whisky has matured enough to be bottled. Thus fortified, we were now ready to tackle the strong winds encountered on the foreshore to the west of Stromness!

Figure 1. The malting floor.

Figure 2. The whisky stills.

© Highland Park single scotch whisky.

The oldest rocks in the area are the Stromness granite gneisses (>700Ma) which were formed in the core of an ancient mountain chain. In a later tectonic episode 420Ma ago, the Caledonian mountains were created by continental collision as the Iapetus Ocean closed. Subsequent rebound, rifting and erosion resulted in an intramontane valley filled initially with coarse-grained conglomerates and breccias. Eventually, as erosion and sedimentary sinking equilibrated the valley bottom became flatter and gently-flowing rivers now deposited finer-grained sediment.

Although this high mountain plain was then situated just south of the equator in a dry desert area, there were also some wet periods when snow and rain brought down by rivers flooded the valley thus forming Lake Orcadie. Fluctuations in climate, due to the orbital forcing of Milankovitch Cycles, produced alternating wet and dry periods, essentially every 100,000 years, which resulted in cyclic sedimentation, i.e. finely laminated, black, muddy shales in wet periods when the lake existed and fluvial sands and silts during dry periods when the lake had all but dried up. Within the Lake Orcadie flagstone sequence (mid-Devonian) 108 such cycles have been identified, representing ~10Ma of deposition.

On Stromness West Shore we encountered first the ancient granitic basement (migmatised to gneiss, containing aplites and pegmatites) which directly underlies Stromness and the nearby hill of Brinkies Brae. John asked us to imagine we were on the island of Brinkies Brae where the waters of Lake Orcadie were gently lapping against the hard granitic shore. We were actually standing on a present day shore where the waves were coming in at quite a pace, piling rocky debris against the granitic bedrock! But the analogy helped us to recognise evidence of sedimentary processes such as imbrication (Figure 3), which we found both on the modern shore and in the nearby basal breccias. A few steps further and a fossil stream was identified in an outcrop at the back of the beach because cross-bedding indicated the stream current direction was opposite to that of the waves which had lined up the imbricated rocks.

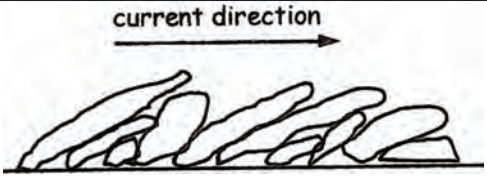

Figure 3. Imbricated pebbles showing current direction.

Walking west along the beach and up the succession, lime muds were found immediately above the breccias and beach sands, representing deep water sediments of Lake Zero deposited from suspension during the first wet period in the 108 lake cycles mentioned above. Then came banded flagstones, storm beach conglomerates and rippled sands leading into finely-laminated silts and dark muds, the first true laminite of Lake No 1. Thus we worked our way up through many lake cycles, identifying the start of a dry period with desiccation polygons (Figure 4), up to 10cm diameter, and/or gypsum pseudomorphs.

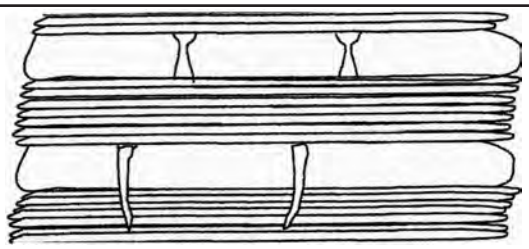

Figure 4. Ilustration of how dessication cracks have penetrated to different levels of underlying sediments during dry periods.

Occasional faults were encountered along the section, usually downthrown to the east and it was noticed that rippled bedding surfaces were giving clues to our position within Lake Orcadie. At Lake Zero the wave direction had been oblique to the ancient island shoreline but by the time Lake 7 was reached further along the modern shoreline we had moved laterally as well as up succession and the ripples now indicated that waves were lapping directly towards (at 90° to) a shoreline, ie. the edge of Lake Orcadie instead of the granitic island.

Often, laminites of a wet period were interlayered with stromatolites. Lakes No 4 & 5 in particular displayed massive stomatolite bodies developed to a size not seen elsewhere in the Orcadian Basin (Figure 5). The modern environmental equivalent is thought to be the Sharks Bay area of western Australia where algal structures flourish because they are hardly grazed by a fish population kept to a minimum by highly saline waters. Figure 5 illustrates how stromatolites grew into erosion grooves, which separated the algal colonies, in order to protect their dolomitic holdfast cores from being undermined, then lake laminites later filled in spaces between the mounds. Also, black chert was found where the massive stromatolite section passed into the sediments of Lake No 6.

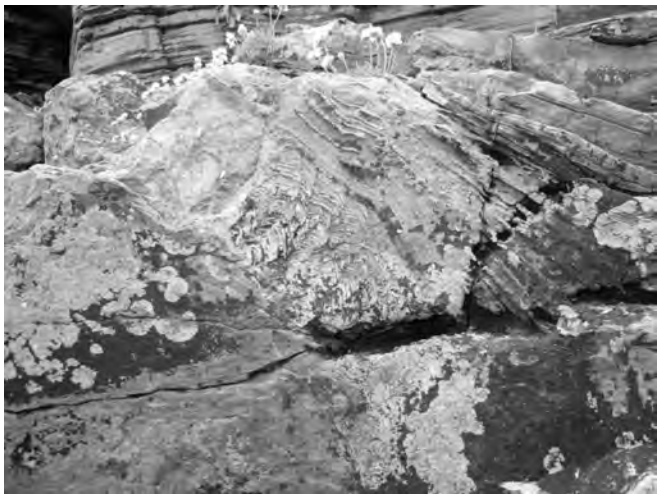

Figure 5. Stromatolites growing down into erosion grooves to protect their holdfast cores with subsequent laminites filling in the spaces between mounds. © Chris Arkwright.

Higher Lake cycles contained progressively more fluvial sediments until eventually the boundary between Lower (which we had been following) and Upper Stromness Flagstone Formations was reached and identified by the distinctive Sandwick Fish Bed comprising a diverse fish fauna, examples of which we would see later at the Burray fossil museum. We also hoped to collect samples ourselves.

Our first day on Orkney had been fascinating. Apart from introducing us to Highland Park, John had taught us to recognise so many details in these diverse lake sediments. We had learned much and were looking forward to the rest of the trip.

Acknowledgement

Apart from my own few field notes, photos and sketches, the above report relies heavily on material gleaned from John Brown's web site and trip field notes and the Highland Park web site.

Chris Arkwright

Day 2 - Hoy Day

We started the day driving through a fairly thick low lying fog, and since all of Orkney is low lying this meant there was nothing to see from the bus. Rachel and John with their local knowledge both assured us that Rackwick bay to which we were headed had its own microclimate and the weather would be different, not sure what, but different. Cheered by this possibility we headed for the ferry to the island of Hoy.

After one of the smoothest 30 minute ferry crossings I have ever encountered we set wheels on Hoy. At the north-east end of the Rackwick valley we stopped the bus so that John could set the scene for us. The Rackwick valley bisects the hilly topography of Hoy from north-east to south-west along the Bring Fault line. The eastern side of the island borders the anchorages of Scapa Flow and the western side faces the Atlantic. During the last ice age a 1-2,000m thick ice sheet existed in Scapa Flow, which sent fingers of glacier into any surrounding low lying land; in the case of Hoy, into the fault formed Rackwick valley. He tried to point out the U-shape of the Rackwick valley, but was defeated by the fog, but was able to show from this vantage point the trim line that the glacier had left on the hillside, showing us its maximum height above the floor of the valley.

On our way through the valley to Rackwick Bay at its south western end we were able to see lateral moraines lining each side of the valley, and the fog cleared to show us the characteristic U-shape left by a glacier. Stopping by an exposed lateral moraine, we sifted through the rubble and found only local stone, this proved to us that the glacier had not come from far away. Further down the valley a broad, well spread out, terminal moraine could be seen covering the valley bottom, and just beyond this, and only a few hundred metres from the beach at Rackwick Bay, an outwash plain (Figure 6).

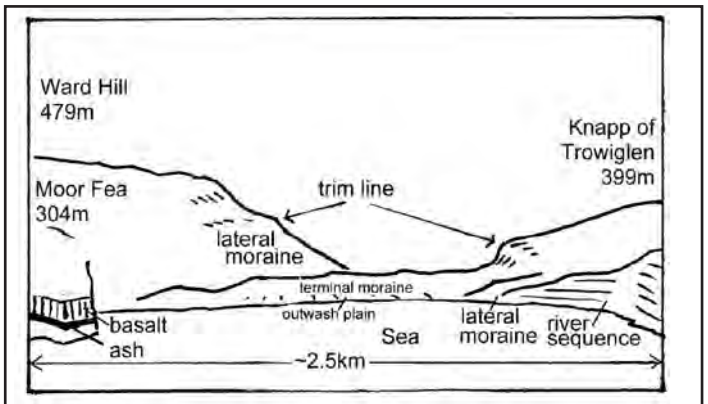

Figure 6. Sketch of Rackwick Bay looking north-east. © Linda Smith.

As we approached the beach parking area the promised microclimate took effect, brilliant sunshine and a fierce wind, at least we could now see what was being pointed out! We left the glaciated valley for now and clambered over the sea wall of sandstone, basalt and bright, brick-red stone, found stepping-stones over the burn, and was met by a blast of dry beach sand. So we stopped for a moment to study present day aeolian dune formation in miniature, before turning our attention to the rocks.

Firstly we were directed to look at the headland at the NW end of the bay, and pick out a bright red layer close to the water. This is a layer of volcanic ash which forms a local unconformity on Hoy, and is the origin of the very rounded, brick-red stones on the beach. Below the volcanic ash is the Upper Stromness Flagstones that lie above the Sandwick Fish Bed seen yesterday. Above the volcanic ash is a layer of basalt, with columnar jointing, evidence of a volcano in the middle Devonian, and according to the geological map that we all picked up at the fossil museum yesterday, dated at 379± 10Ma (Halliday *et al.*, 1999).

At the south-east end of the bay is a cliff with a nice exposure of Hoy sandstone, which lies above the Hoy volcanics, and also shelter from the wind.

This part of the sea cliff is about 3-4m high and around 10m in length and easily accessible. We are told that it is a river bed with cross-stratification, current ripples, channel lag and mega-ripples, and we should go and find them, and also to work out which direction the river was flowing. Notebooks, pencils and of course cameras came out and we spread out along the cliff.

After a pleasant half hour in the now very warm sunshine, John picked a section of cliff, called to us to gather around, and pointed out all the mentioned structures. A mega-ripple with a channel lag deposit just above it (Figure 7). A mega-ripple forms at a time of flood when the water is deep and fast-flowing and a large sand dune forms (Figure 8). The channel lag is a coarse-grained deposit formed in mid channel where the largest boulders can be carried, and left behind if the current wanes. Cameras click, sketches are drawn. The river was flowing north-east into the cliff.

Figure 7. Channel lag and mega ripples. © Linda Smith.

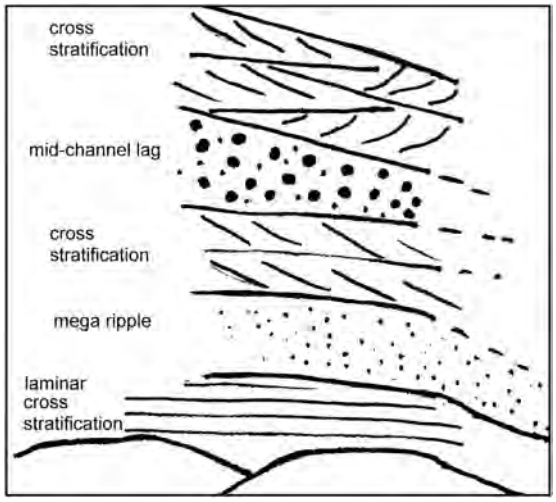

Figure 8. Sketch of river structures in Hoy Sandstone. © Linda Smith.

Above the cliff we met the glaciation landscape again and can see that we are standing on the lateral moraine on the SE side of the Rackwick Valley. But look again, the outwash plain and terminal moraine from the Rackwick Valley glacier is a couple of hundred metres further up the valley. This small lateral moraine, showing a much lower trim-line, must have come from a small finger of glacier entering Rackwick Bay from the Pentland Firth to the south-west. So we have evidence of ice sheets producing glaciers in Scapa Flow to the north-east and in the Pentland Firth to the south-west, meeting at the lower south-east end of the Rackwick valley.

Lunch was on the bus which was parked near some public conveniences; the most serious drawback of Orkney being the absence of bushes and trees. In a valley joining the Rackwick valley is Berrie Dale Wood, a few small hazel, birch and alder trees that are one of the few remnants of the original Neolithic forest that once covered the whole of Orkney. This woodland and meadow would have been extensive enough to support red deer and provide hunting grounds to supplement the Skarra Brae farmers.

On the way back up the Rackwick valley the now brilliant sunshine gave us an excellent view of the glaciation features that were only explained to us on the way down. We stopped to view a corrie, the birthplace of a very small, short glacier which nevertheless was a textbook armchair shape, with near vertical back wall and sides, and a lip over which the glacier had left its corrie and joined the main Rackwick glacier.

Since we were passing, a few of us took a side excursion to see the Dwarfie Stane. A burial chamber that is hollowed out of a sandstone erratic left by the glacier just below the trim-line, and one of the main cultural and archaeological sites on Hoy.

One more geological feature was left to see today, and for this we turn north out of the north-east end of the Rackwick valley, around Ward Hill and into the next valley. This originally had a moraine dam holding a small lake, but is now a reservoir. Sitting on this dam looking north, we see a round, grass covered hill which we are told is dolerite, the plug in the vent of the volcano. We have found our middle Devonian ‘smoking gun’.

A few spare minutes spent in the Scapa Flow Visitors Centre reminded us that the anchorage provides a tremendous Naval advantage and that many ships and men have been lost in and around it. Then onto the ferry and back to Stromness. A very interesting and enjoyable day.

Linda Smith

Day 3

While it was so hot down in the North West of England that people could imagine herds of wildebeests sweeping by, up here in

Figure 9. Natural arch at Yesnaby. Photo © Rachel Jackson.

Orkney it was both beautiful sunshine and a perfect temperature for a field day on and around the Yesnaby cliffs (Figure 9).

Initially we looked not at rocks but at *Primula scotica*. This rare flower is not only one of Britain's few endemic species but unusually flowers twice a year so if you are lucky enough to be up there in July you might see it then too.

John, our leader had mapped some of this area for BP so for complete novice mappers this was a fascinating introduction to mapping and the professional approach to it. Observation definitely seems to be the first rule. Normally a series of traverses would be made, making notes at all relevant points. We were advised to note what we saw, looking for variations, for example, where flagstone ended and sandstone started and to keep our eyes open for possible contacts. The easiest places to map are windswept ridges where the rocks are more exposed.

There were a lot of basic concepts to keep in mind. If you are looking at a rock there are just two natural reasons for it being where it is: it has either always been there or it has come from above. A new term to many of us was float. Rocks have a propensity to rise (float) up from the basement. The analogy was made (and verified by the farmer's wife present) with farmers clearing their fields of rocks only to find more rocks the next year. There is always a possibility of erratics so proportions of rocks found have also to be considered. Using the float idea Martin spotted just a few pebbles of basalt (who said Orkney was just sandstone) that indicated a trap dyke beneath the sediment. This dyke we later saw exposed at the cliff face.

The bedrock was identified as a two-feldspar granite and we looked for contact between this and the Harra Ebb formation of breccias, muds and conglomerates and the sandstone. This was named after Harray, the only land locked parish in Orkney. Contact was also seen between the granite and the sandstone indicating an unconformity, where the Harra Ebb had been eroded before the sandstone was deposited. By looking at contacts, relationships and dips we found the zero edge of the Harra Ebb where it went from this to the Stromness flagstone.

We also saw evidence of a fault. This we later saw at the cliff edge directly beneath the only other person we met in this area, who suddenly found fifteen geologists staring in her direction.

Incidentally BP thought that there might be up to a million barrels of oil here but Orkney never did become Texas, it is too windy to wear cowboy hats.

Enough mapping for today, we still had carpets of pink thrift and pale blue squill to walk over as we looked at the Atlantic Ocean meeting the Old Red Sandstone which formed caves, sea stacks and geos, the Orkney name for a narrow inlet, pronounced giyo. Layer upon layer was exposed indicating when the area of ancient Lake Orcadie had been a true lake, mud flat or desert. Darker rocks indicated quiet deep water, paler ones more turbulent times and light, fine sand the lake margins.

Particularly striking were the aeolian formations. These are distinguished from the lacustrine ones as they are larger, concave rather than planar and as the wind blows from all directions the bedding is more random.

We also saw a flow of Harra Ebb that had clung to the granite island and then thinned at the base. There were also volcanic features, the granite base and some dykes, including a composite one with an acid centre and basic sides. Also coming through the sediment was a small amphibolite dyke. This being geology there were also a few unexplained features like a pillar made of rocks and Yesnaby sandstone.

It is a maxim of geology that the present is the key to the past and often what we had seen today mirrored what was happening in the Devonian when the granite was exposed and its crevices then as now were being filled with sandstone.

After looking at enough geology for a year's course it was only just time for, an admittedly late, lunch before moving to another part of the cliffs and an SSSI, Site of Special Scientific Interest, to see stromatolites. These were horse teeth stromatolites that to me first looking at them from above did not look like horses' teeth at all, whereas once I had seen them from the side I could not see them as anything else (Figure 10).

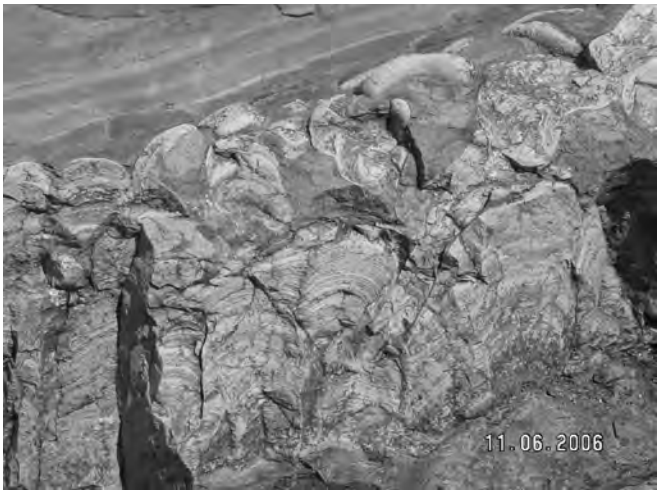

Figure 10. Section through a Horse Tooth stromatolite showing the curved tops to the 'teeth'. Photo © Rachel Jackson.

Relentless and desperate for a toilet stop we moved on, this time for some archaeology and the oldest and best-preserved Neolithic site in Europe, Skarra Brae. Sand deposition covered and preserved it and erosion blew the sand away just as there were archaeologists around to appreciate what it was. Geologists are often exhorted to use the eye of faith but it is nothing to the faith and imagination archaeologists must have to reconstruct ancient villages. It is a fascinating site in a beautiful beachfront location and well worth the visit. The visit also included Skaill House, the home of the laird who discovered Skarra Brae and is crammed with items collected by the 12 lairds of Skaill.

This was definitely our busiest day and with so much to see, all those hours of daylight to see it in and with organiser and leader both keen to show us their island we had much more in store.

Our next stop was Cruaday quarry to meet again some familiar fish faces from the middle Devonian. The Sandwick Fish Beds are quarried here for flagstones (Figure 11). It was very easy to find the shiny black fish parts, with most clearly showing scales, *osteolpis* was spoken of with the familiarity of cod and everyone found something worth taking home and many just enjoyed the opportunity to whack away with hammers. The quarry manager's slow work with hammer and chisel to get a larger piece down to

Figure 11. Fishing at Cruaday quarry. Photo © Martin Elsworth.

a more manageable size indicated that whacking, although fun may not be the best method.

The day still held another treat and with lochs or sea to be seen all around, and with the sound of larks overhead we visited the Ring of Brodgar. This is a mini Stone Henge type stone circle but without tourists, motorway noise and entrance fee. Fortunately for the inhabitants of Orkney we were a few days early for the summer solstice thus sparing them the sight of one member of our party who would have seized the opportunity to comply with custom and dance naked around it on mid-summer's eve.

A full day and still no sign of a dark night but unquestionably time for a Dark Island, the Orkney's special brew.

Anne Lavelle

Day 4

For our final day we once more sallied forth for our packaged minibus trip, this time to Kirkwall. Some went shopping, but the more dedicated had time to explore the museum and the cathedral.

The museum contains a box in which the remains of St Magnus were found during restoration in the early 20th century. The skull was cleft by the axe that killed him. The exhibition gave a good picture of Orkney and its customs.

Walking round the cathedral Jenny, Martin and Gerry met Colin Watson, the cathedral mason. Working from his shed in the grounds, latterly on his own, he has spent 21 years repairing and maintaining the fabric of the cathedral. We discussed the rock types used and their properties. The beautiful red stone, which contributes to the charm of this cathedral, was and is quarried not far from Kirkwall at Head of Holland. It is an aeolian sandstone showing the cross bedding typical of dune bedded sandstones. Colin explained how the variation in the stone caused problems when cutting it. This meant that chisel sharpening was needed very often. The enclosed mud flakes in the stone not only indicated occasional wetter periods during deposition but also weathered out to leave holes in the masonry. The cream coloured stone used for example in the door arches has a fluviatile origin and comes from Eday. This is better-cemented and easier to work. We looked at the south doorway where the cream has been replaced leaving the red looking rather tatty. Flaking is a problem, which leads to moisture and frost further damaging the stone. Deflaking or sometimes the use of glue as a temporary measure deals with this. Interesting to talk to a dedicated mason - but as he works alone, will his skills be lost when he goes? Hopefully, not for a long time.

Inside the cathedral is a wonderful Portland stone memorial to John Rae. He was born at the Hall of Clestrain in Orkney, worked for the Hudson Bay Company in Canada and inter alia, searched and found evidence for the fate of Franklin's expedition in his quest for the North-West Passage. Traces of cannibalism relating to Franklin's [~1845] expedition and found by John [in 1854] did not endear him to Lady Franklin. A marble cross at the back of the graveyard marks John Rae's grave. It records some of his exploits.

We regrouped at 1.15pm for a trip to Birsay Bay. Undismayed by our cerebral torpor our valiant Dr John Flett Brown again hoped that we could display our skills in the field. The Sandwick fish bed was our starting point. A very obvious *Coccosteus cuspidatus* was immediately recognised (by John) from its appearance edge-on, in the cliff. We agreed with him. We walked north towards Brough Head. Crossing the Upper Stromness Flagstone Formation dipping at about 20° to the north-west. We progressed through 14 cycles. Each cycle lasted about 100,000 years and represents rhythmic sequences of deposition in a lacustrine environment (the Orcadian Basin) during Devonian times. Each sequence begins with thinly laminated varves of blue mudstone followed by siltstones and then fine grained sandstones. The sequences here are thicker than in the beds below the Sandwick Fish Bed, around 15-18m. Current bedding indicates infill from the northwest, increased erosion giving more sediment to account for the thicker beds. A normal fault with downthrow to the southeast and a soft sediment decollement indicate crustal extension. This is related to a rebound of the lithospheric plates following the Caledonian Orogeny when the Iapetus ocean closed. Fish remains were found in most of the laminated sequences perhaps indicating less saline conditions as the lithospheric plates drifted north. A lens of blue, limey, phosphatic, mudstone with fish remains was found amongst a sand silt sequence. It may have been a pool in which surviving fish enjoyed a final thrash before it dried out. Higher up the cycles mud cracks made their appearance showing that some drying out had occurred. Milankovich would have been proud to have these sequences attributed to his cycles.

The party now divided with some viewing the archaeological site at Brough Head and others to the museum at Stromness. Here there were good fish fossils including *Homeosteus milleri* found by Hugh Miller during his preaching and geologising. The Diorama of John Rae in his inflatable Halkett boat of 1853 is a reminder of his strength and resilience due to his Orkney breeding. I walked on to Loggins well where many of the Arctic ships, including Franklin's, watered before their voyages.

Gerry Shaw

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Thrombolites in danger – Lake Clifton, Yalgorup National Park, West Australia

M Rosemary Darby

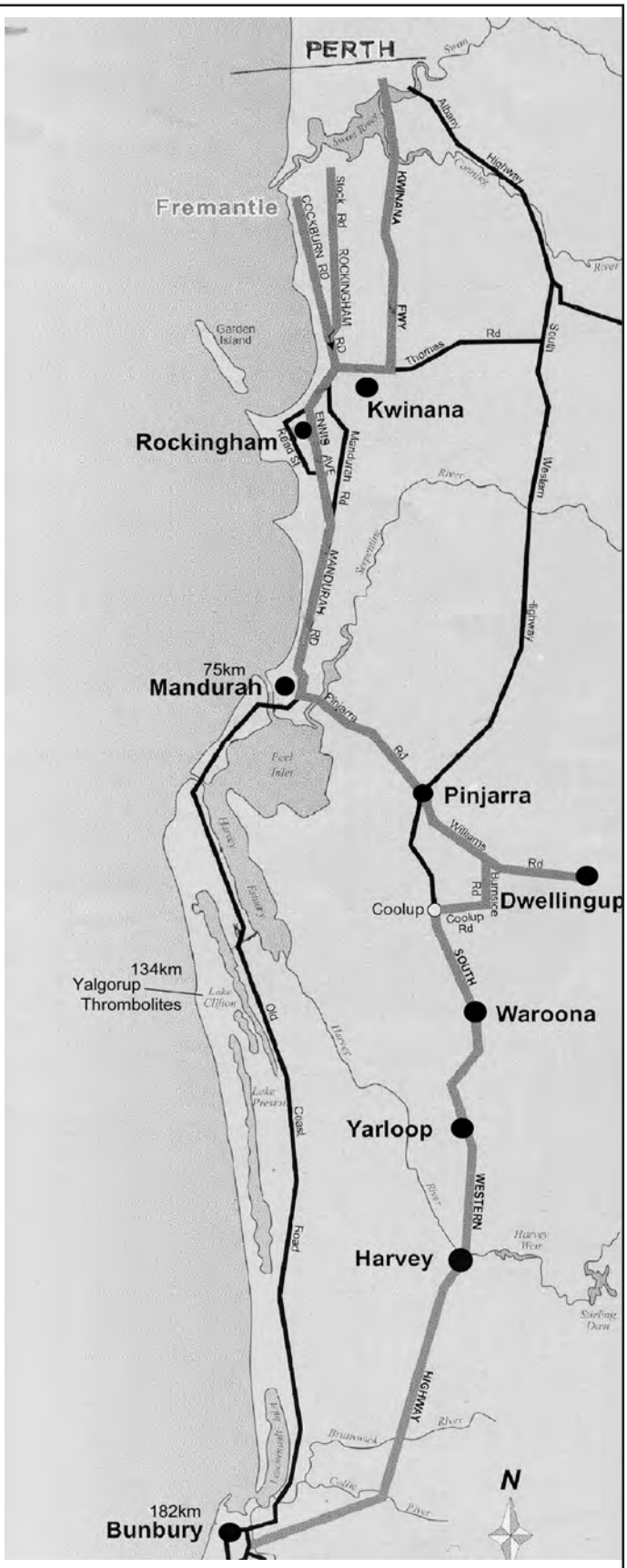

Figure 1. Map from local tourist leaflet; distances south of Perth.

One hears of Stromatolites with reference to the Pre-Cambrian fossils of Australia – Thrombolites were new to me. Both species are microbialites, but form differently.

With Stromatolites, sediments are trapped by mats of gelatinous slime, forming a laminated internal structure.

Thrombolites have an internally "clotted" structure where, as micro-organisms photosynthesise, $CaCO_3$ drawn out of the high lime content lake water precipitates and forms into a rocklike material, growing about 1mm per annum.

About 600Ma Thrombolites were common – fossils may be seen today in the Amadeus basin in Northern Territory, Australia. Stromatolites can be found in Shark Bay, Western Australia.

Thrombolites and Stromatolites were the only known forms of life on Earth some 650 to 350Ma ago. Micro-organisms found in both thrombolite and stromatolite formations are believed to be responsible for oxygen production, which allowed life to develop as it did on the planet.

Thrombolites, 'living rocks', are the most common form of microbialites, which are rock-like structures built by micro-organisms. One of the few places in the world where the thrombolites grow is at Lake Clifton in Western Australia's Yalgorup National Park (Figure 1). The lake is also one of only two sites known where microbialites occur in water less salty than sea water.

About 80 miles south of Perth, West Australia, - the name Yalgorup meaning "place of waters or lakes" in the Noongar Aboriginal language - the Yalgorup National Park was established in the 1970s to protect the coastal lakes, swamps and tuart woodland in the area. An observation walkway has been constructed to allow visitors to view these fragile structures (Figure 2).

Figure 2.Viewing walkway showing normal depth of water.

Lake Clifton is one of a series of lakes lying between low sand and limestone ridges running parallel to the Indian Ocean. During the Ice Age, about 225,000 years ago, much of the ocean was ice, shorelines receded and a new dune system, created by wind and waves, trapped water to form a lagoon (Figure 3).

Today there is a chain of about twenty lakes and wetlands, preserved as an undisturbed system with its wetland vegetation and wildlife, particularly water birds. The area is also central to waterbird migration patterns (Figure 4).

Figure 3. Shallow water and mud – West by North.

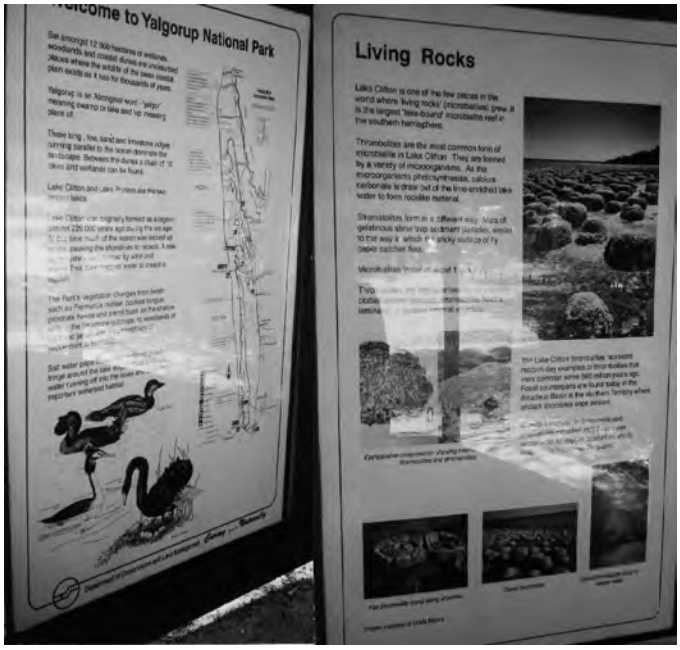

Figure 4. Park Authority information boards.

Figure 5. Coiled Thrombolites west of viewing platform.

Lake Clifton's Thrombolites form the largest lake-bound microbialite reef in the Southern hemisphere - over 6kms long and widening in parts to 120m. The thrombolite structures reach heights of up to 1.3m.

There are three basic forms visible from the viewing platform:-

1) flat doughnut shaped or coiled type, found along the shoreline (Figure 5)
2) dome-shaped type
3) conical type found in deeper water.

Figure 6. Receding shoreline – view to East by South.

Because of a grave lack of rain in recent winters, the shoreline is receding and this is of great concern to local naturalists.

As "living rocks" the structures must have water in order for the micro-organisms to photosynthesise and draw the $CaCO_3$ from the water. Here, at lake Clifton, the upwelling of fresh ground-water is high in calcium carbonate, an ideal environment.

Without adequate rain the shore-bound and shallow water structures are likely to die and more of Australia's natural heritage will be lost.

References

Research done on line and found in tourist articles and research papers through both Answers.com and Wickipedia search engines. No particular site had enough information to supplement that found previously for a wall display, most of which came from a friend's library of booklets and the Department of Conservation and Environment, Yalgorup National Park information boards.

Anyone wishing to look at the sources, type "thrombolites" into any search engine – there is a lot of information but seemingly not detailed enough from a scientific point of view. Any readable Scientific papers did not answer my questions.

Footnote

Lake Clifton is named for Marshall Clifton (1787-1861), who originally arrived in Western Australia to manage the settlement scheme at Australind, and later a member of the Legislative Council.

Explorers Dr Alexander Collie and Lieutenant William Preston RN first came across what are now Lakes Preston and Clifton while exploring the coastline between Mandurah and Bunbury in 1829. After the introduction of convicts to the Swan River Colony in the 1850s, the "Old Coast Road" south of Mandurah was rebuilt. For most of its length, the road went through well-timbered, sandy limestone country of little value to agriculture. The area's first European settler was John Fouracre, who built a house in this area in 1852 and had established a wayside inn and changing station at Wellington Location 205 in 1854.

The townsite of Lake Clifton was developed in 1920 as a result of the W A Portland Cement Co. seeking to mine a lime deposit there. For a short period it was a busy company town, but the mine closed at the end of 1923.

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Photographs © MRD 2002.

Intrigue at Belmont Hamlet

Rob Heslop

I have searched for fossil ammonites for many years and find them simply remarkable; they are both beautiful and puzzling. I used to read ravenously about them, flicking through descriptions eager to identify the latest specimens that I had recovered. I learned their scientific names, and in the process began to understand geological timescales; this led to a passion for geology maps. I once found an old and ragged map in a second hand market, and whilst glancing over faded contours could clearly see sedimentary strata which seemed promising for Jurassic fossils in the Golden Stone Hills, north of the French city of Lyon.

I later explored that area and indeed found many visible Jurassic seams scattered around the vicinity. Walking east to west, I recognised the Sinemurian strata on the outskirts of one village, and later Toarcian horizons on the outskirts of the next. And whilst nearing Belmont hamlet I got to the Bajocian; yes, I was indeed walking through time, but at this point could walk no further, for I had arrived at the high wire fence of the local big Lafarge quarry. Inside that quarry I longed to be.

It was initially the British engineer, William Smith who recognised that specific fossil species are contained in specific strata. Later, the interpretation of this led him to recognise individual biostratigraphies and thus to unravel a basic chronological order within geological horizons. The true age of the Earth however, was only fully understood 50 years later.

Smith proceeded to record the geology of the south of England, and published his work in 1815. Following his example R Murchinson and A Sedgwick had, by the mid 19th Century, also mapped large areas of Britain.

In France G Cuvier had established similar work and A Brongniart was by this time mapping the Paris area. And it was the French naturalist E Dumortier who, by 1874, had identified numerous ammonite species and was using 'Smithian Principles' correctly to demonstrate those ammonites, notably the *Hildoceras bifrons*, as being unique to the red Toarcian strata, a sub division of the Jurassic period.

Indeed, ammonites and especially the many variations of them, proved a most useful identifier toward correlating strata throughout the whole secondary geological scale.

De Riaz was to add to this knowledge, completing the work of Dumortier before identifying yet another zone ammonite, the *Pleydellia aalensis,* and in doing so establishing it as a younger sub-strata species than the hildoceras-zone; so even the sub-period of Toarcian was being further sub-divided; I found, and read his work, which was published in 1913. Enthralling, it reads like an adventure story. Today the Toarcian stage is known to separate into 8 zones, and further divides into 20 smaller sub-zones.

The ammonite cephalopods spread throughout the oceans of the world as early as the Devonian Period, 400Ma ago; evolving and dividing into countless sub-species millions of years later, especially during the Jurassic, before rapidly declining toward total extinction at the end of the next major sequence, the Cretaceous period, sometime before the great dinosaur extinction. Why the ammonites diminished remains unexplained; it is this factor that fires interest towards them.

It was during a cold winter morning that I at last had the opportunity to visit that quarry. Very early that morning, I met up with a small group of friends at the quarry entrance and armed with pickaxes, shovels and hefty rucksacks, we boarded a Land Rover and drove almost a mile through the quarry, before arriving at the large mound of rock and rubble and mud that had been piled and left for us the previous day. This was a Monday bank holiday, there were no trucks, no diggers, no noise. In fact the only person on site apart from us, was the entrance security guard.

We spent our time digging through the heap as big, heavy ammonites fell from the muds; some of them rolling out like lost car wheels. I caught one rugby-style as it rushed dangerously down; it was a large and fabulous *Lytoceras cornucopiae* (Plate 4a).

At one moment, I spiked a chunky rock with my pickaxe and dragged the lump from the diminishing pile; another perfect large *Lytoceras* ammonite had been fished, and indeed saved; for on a normal day within this quarry, all stone, whatever shape or form is collected and crushed into cement powder. Other, smaller shells surrounded this spiked, central ammonite.

Later, we found a beautiful *Pseudolillia* which bore the deep tooth marks from the marine reptile that had sank the victim to the depths, 170 million years before; a bizarre worm (shelled; anthropod or annelid?) was neatly preserved upon its shell, (Plate 4b) remarkable indeed, but there was more to come as we went on to discover a tennis-ball sized *Nautilus* fossil (Plate 4c).

Somewhat similar to ammonites, nautiluses meandered the seas, moving blindly backwards and sprinting rapidly when needed by squirting water from a mouth-piece siphon.

These animals are truly bewildering; it is indeed from them that the ammonites probably descended, and it is only the nautiluses that actually still survive to this very day, as 'living fossils'… and seemingly they remain unchanged from their earlier Devonian ancestors. Evolutionary biologist R Dawkins pondered upon the nautiluses, describing for example their peculiar primitive eyes, which have no lenses. This absurdly renders vision most inadequate within their aqueous environment; surprisingly then, during this massive lapse of time their eyes have remained underdeveloped, even to this day. Yes this, an albeit rather poorly preserved fossil specimen, is an evolutionary exception; how did they manage to traverse the ammonite mass extinction event? Intrigue indeed.

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Author

Rob Heslop lives in a French village south of Lyon, with Anne and their three children. He works as an English teacher, is currently studying archaeology (prehistory) long distance with Exeter university, and is on a science short course with the Open University studying Mammals. He writes many short articles concerning landscape and prehistory, and participates on many archaeological digs. To counterbalance these activities he is entirely renovating his 17th C, 5 bedroomed house.

Book reviews

The Geology of England and Wales 2nd Edition by Patrick J Brenchley & Peter Rawson (Eds) 2006, The Geological Society, 559pp, £35.00 (Paperback) ISBN 13-9781862392007 £85.00 (Hardback) ISBN 13-9781862391994

There has been no change in the pace of geological time since the publication of the first edition of this book, but pace of increase in geological knowledge continues to increase and there have been significant developments in our understanding of geological processes. This new edition attempts to accommodate the new understanding and the huge increase in the available database on British geology.

The work is produced on a stratigraphical basis and organised as an account of the evolution of the area with chapters arranged on a temporal basis. In the first chapter the editors provide us with a brief description of England and Wales through geological time, summarizing the global setting and key events in the geological evolution. They also include, side by side a copy of William Smith's 1815 map and the current geological map for comparison. Within the summaries they cross refer, where appropriate, to the relevant chapters. The subsequent chapters cover the geological periods and major events. In addition to each chapter title indicating which period is covered, a subtitle provides a short description of the overall environment. In an attempt to integrate as many aspects of geology within the chapters there are no separate ones on structure, igneous rocks or off shore geology but there are chapters on the main orogenic episodes and the phases of major intrusions. Economic geology has also been omitted but details included in relevant chapters. A short but comprehensive chapter on Cornubian granites and mineralization of SW England will be of particular interest to those with an interest in the Southwest. Another major addition is the final chapter which explores the future with particular reference to climate and sea-level change, glaciation and the current northward drift. This chapter concludes with a brief exploration of possible future continental distributions up to 200 Ma ahead.

With many clear and well-produced illustrations and a useful set of colour plates to complement the text plus a comprehensive reference list, this book is an excellent resource for Earth scientists being a useful starting point for the study of our countries' geology.

Mike Hermolle, BSc (Hons) NatSci (Open)

The Box Hill and Mole Valley book of Geology by Richard C.Selley, 2006, Friends of Box Hill, Pixham Mill, Dorking, Surrey, RH4 1PQ, pp, 38, £4.95 (paperback) ISBN 095344306-X

Box Hill is a prominent Chalk landmark on the eastern side of Dorking in Surrey and north of the River Mole. South of the river are Leith Hill and Ranmore Common, outcrops of the Lower Greensand. The River Mole flows from the east, south through Redhill, then West and North at Box Hill, thence through Leatherhead.

The origin of this book was in a lecture, "Mole Valley Rocks", for a 2005 Heritage weekend. Because the chosen venue was too small for all those who wished to attend, the lecture was repeated several times in the Dorking area. Students of Ecology may have attended Juniper Hall Field Study Centre on Box Hill for their residential week. Because of the local interest, the group "Friends of Box Hill" asked for the lecture to be made into book form, to join several other booklets they publish on the area.

It is a nicely produced booklet about 8ins/ 20cm square and slim enough to take out in the field. It is well illustrated, the majority of the illustrations being by the author. Compiled for the general reader, the Foreward and Preface provide a gentle entry to the subject.

The Introduction suggests the origins of the names "Box", "Mole" and "Ranmore". The next section covers sedimentary strata with useful maps, stratigraphic log, fossil drawings, micrographs and "geophantasmograms" – often in 3D. Uplift and erosion are covered, followed by glaciation. A section on the local economic resources leads in to a look to the future, with camel trains crossing a Wealden Sand sea from ports such as Lewes, the original ports having been inundated and the Thames barrier breached in 2025.

The booklet concludes with a useful section of FAQs, Glossary, References, web links and, on the inside back cover, Keele University version of the GB Geological map with time scale, stratigraphic column and key fossils.

Richard Selley is Emeritus Professor of Geology and a Senior research fellow at Imperial College, who has lived in the Mole Valley for most of his life.

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